

AIR DEFENSE OPTIONS FOR TAIWAN

An Assessment of Relative Costs and Operational Benefits



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Preface

This report assesses different air defense investments that Taiwan could make and analyzes them in comparison to current People's Liberation Army (PLA) capabilities. It begins with a description of the PLA air-power threat and how it could overwhelm Taiwan's current defensive capabilities, describes a set of force structure options in a cost-constrained environment, and compares those options using several vignettes that highlight key operational differences. The analysis provides a basis to inform decisions about a direction for Taiwan's defense program to meet current air defense challenges. These involve not only new systems but also new concepts for employment. This should be of interest to those in Taiwan concerned about defense issues and to those in the United States and other countries who care about Taiwan's security and the overall security of northeast Asia.

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Summary

Taiwan faces one of the most difficult air defense problems in the world, and, because of that, it cannot easily look to how other nations have invested in air defenses to guide its force structure decisions. What makes Taiwan's air defense problem so difficult is the combination of its proximity to China, coupled with the massive investments that the People's Republic of China (PRC) has made in a range of systems that threaten Taiwan's aircraft—not just while they are in the air but also while they are on the ground.

If a major conflict were initiated, China now has the capability to destroy all of Taiwan's aircraft at their bases, except those that can be hidden in Taiwan's two mountain shelters—but those protected aircraft might provide little solace because, although the aircraft might be safe in these caves, Taiwan cannot use them from those shelters for sustained combat operations. Thus, Taiwan needs to rethink how it can accomplish its air defense goals in a major conflict without heavy reliance on its fighter aircraft.

Fighter aircraft are not the only element of Taiwan's air defense; surface-to-air missiles (SAMs) are the other major element. Here we see more promise, *if* Taiwan can both use its SAMs to their best advantage—that is, against aircraft and cruise missiles, not primarily against ballistic missiles—and employ them in a way that increases their survivability—that is, by operating them for short periods of time, followed by rapid teardown and movement. Used in this way, Taiwan's SAMs could become an important contributor to the defense

of Taiwan and a difficult capability for the People's Liberation Army (PLA) to easily counter.

Still, air defense in a major war is only one possible category of demands for Taiwan's air defenses. A variety of more-limited military conflicts could draw on air defense capabilities. We found that, in these coercive situations, if the level of violence is relatively high, the PLA could check Taiwan's fighter aircraft if it chose. However, in coercive scenarios that feature very constrained use of force, Taiwan's fighter aircraft can play a role in countering aggression. The question is whether maintaining that limited capability is worth the major financial investment that it entails.

This report analyzes Taiwan's options for allocating future resources for air defense capabilities. We describe the essential air defense problem posed by the PLA, characterize the current capabilities and level of funding that Taiwan invests in air defense, and then develop several alternative investment strategies. We then test those investment strategies in three vignettes that span the range of conflict, from quite limited coercive uses of force to a full invasion.

The Air Defense Problem

Over the past 25 years, China has made investments in ballistic missiles, cruise missiles, antiradiation weapons, and increasingly sophisticated fighter aircraft to thoroughly threaten Taiwan's air defenses from end to end. In these 25 years, Taiwan has gone from having a qualitative advantage over the PLA in the air, to its current situation, which we assess to be grim indeed. Looking first at threats to aircraft and then to SAMs, we explain why we come to that judgment.

In the age of precision weapons, aircraft operators need to be concerned with threats not only to their aircraft while flying but also to their aircraft while on the ground and to the air bases that allow them to generate high sortie rates.¹ Air bases are obviously fixed targets, so an

¹ John Stillion and David T. Orletsky, *Airbase Vulnerability to Conventional Cruise-Missile and Ballistic-Missile Attacks: Technology, Scenarios, and U.S. Air Force Responses*, Santa

adversary with weapons that can range an air base is likely to know, in great detail, the attributes of each base and be sure to have a diversity of systems able to target their key attributes. For example, an adversary could target fuel to limit the capacity of a base to sustain operations, or it could target runways to immediately cease flight operations. Alternatively, the aircraft themselves could be the targets of attack while on the ground.

Although these attacks could be quite devastating on their own, China also has the capacity to capitalize on them in several ways. For instance, it could launch pinning attacks against fighter bases to cut runways and strand aircraft. These could be followed by sweeps of fighter aircraft targeting stranded aircraft on the ground.² The PLA's air-to-ground weapons are accurate enough to be reliable in such attacks. Taiwan does have some concrete aircraft shelters, but, as the Iraqi Air Force learned in previous conflicts with the United States, cruise missiles and other precision-guided munitions (PGMs) can defeat aircraft shelters. One weapon with a 3-m circular error probable (CEP) can destroy a standard shelter. Five Su-30 aircraft, each with ten PGMs, can potentially attack 50 shelters if they are left unmolested to attack multiple target areas. Under such conditions, the PLA fighter-bomber force might have success comparable to that of American aircraft over Iraq in 2003, where targets were struck at low cost and to great effect.

The aircraft themselves could also be targets for ballistic missiles, and Taiwan faces equally grim prospects in this regard. Using submunitions to cover parking areas, two to three dozen short-range ballistic missiles (SRBMs) could hold at risk all aircraft parked in the open at an air base. This would require more missiles overall to attack all ten military air bases (240 to 360, compared with a demand of 40 to 310 for the runway attack case, depending on missile accuracy); however, it holds out the prospect of permanently removing those aircraft without

Monica, Calif.: RAND Corporation, MR-1028-AF, 1999; Christopher J. Bowie, *The Anti-Access Threat and Theater Air Bases*, Washington, D.C.: Center for Strategic and Budgetary Assessments, 2002.

² Roger Cliff, Mark Burles, Michael S. Chase, Derek Eaton, and Kevin L. Pollpeter, *Entering the Dragon's Lair: Chinese Antiaccess Strategies and Their Implications for the United States*, Santa Monica, Calif.: RAND Corporation, MG-524-AF, 2007.

the aid of fighter sweeps, rather than just the temporary suspension of operations that runway cuts would achieve.

Although, for the future, we see a potentially increased role for SAMs in defending Taiwan against air threats, they too have vulnerabilities, which China has made investments to exploit. Radar is the Achilles' heel of SAMs. A SAM needs radar to identify, track, and attack air threats, but an emitting radar is like a bright neon sign and will quickly draw the attention of attack systems. China has numerous options to target located radars. Loitering antiradiation missile (ARM) weapons, such as the Harpy, in the area could attack on detection. Fixed-wing aircraft in the area could also detect and engage SAMs with air-to-ground ARM weapons. Alternatively, numerous intelligence, surveillance, and reconnaissance (ISR) systems could detect and locate the radar, cuing longer-range strikes from cruise missiles or even ballistic missiles, when the most sophisticated radars, and thus high-value targets, emit. If Taiwan employs its air defenses in what we would characterize as a stalwart defense—that is, actively and persistently, defending a fixed area—those radars will not survive long once the adversary has decided to take them out. Without radar, the battery cannot operate. But we see that, unlike with fighter aircraft, Taiwan could adapt concepts to employ SAMs in ways that could make them survivable enough to make important operational contributions to Taiwan's defense.

Increasing SAM survivability is a vital component of Taiwan's future air defense strategies. Part of the key to greater survivability is to use SAMs to conduct appropriate missions. In a future conflict, Taiwan would get more from its Patriot/TK III SAMs if it seeks to preserve them initially by not using them to defend fixed assets, such as air bases, but instead keeps them concealed until they can be used to support important defensive operations, such as a counteroffensive against landed forces. This choice could be politically difficult because, early in a conflict, when Taiwan is faced with ballistic missile attacks, if the Patriots remain hidden, the public could perceive that Taiwanese forces are not doing enough to protect the island from the missile barrages; however, if Taiwan were to attempt to use its Patriots to try to intercept ballistic missiles, they would soon be exhausted, or more likely

incapacitated when all their radars are destroyed, leading to exactly the situation the PLA is striving to achieve, the elimination of those systems. The Patriots cannot protect fixed installations; at best, they can only raise the cost of attack against those facilities by a few missiles.

Taiwan's Current Air Defense Investments

Given that, in a future high-intensity conflict, Taiwan's air defenses face a daunting threat and its fighter aircraft could face early elimination, Taiwan's existing fighter aircraft will nonetheless command a fairly large fraction of Taiwan's total defense spending over the coming years. We estimate that Taiwan will spend about US\$22 billion in the next 20 years on the fighter aircraft currently in its fleet with no changes, and another US\$3.3 billion to retrofit the F-16 fleet. That is fairly substantial for a military that has averaged about US\$10.5 billion in total annual spending in recent years. An assessment of what that investment achieves for Taiwan, from an operational perspective, appears relevant. To do this, we postulated several different alternative future force structure options. The options contain a mix of current fighter aircraft and new aircraft, as well as different SAM mixes. Among the SAM options is a new concept we are calling air defense platoons. These are based on an air defense system being developed by the U.S. Army, which connects a modern Sentinel radar with truck-launched air defense weapons. When operated in combination with Patriot/TK III batteries, it provides a layered air defense against threat aircraft. The four options are

- Baseline, which includes Taiwan's entire current fleet of 328 aircraft, made up of retrofit F-16s, indigenously produced F-CK/IDF aircraft, and French Mirage 2000-5 jets
- Mixed Force, which keeps the retrofit F-16s but retires both the Mirage and F-CK fighters from the fleet and uses savings from those retirements to invest in four additional Patriot batteries and 21 air defense platoons

- Joint Strike Fighter (JSF)—Only Force, which retires the entire current fleet but invests in 57 new JSF short takeoff and vertical landing (STOVL) variants. Although Taiwan has not requested and the United States has not offered JSF aircraft, including them in one option allows us to explore the potential value of this hypothetical direction for the Taiwan air force.
- SAM-Dominant Force, which retires the current fighter fleet, retaining and retrofitting only 50 F-16s, while making major investments in the SAM force, to include 13 new Patriot batteries and 40 air defense platoons, along with the networking capability to achieve a common operating picture for all air defense assets.³

Table S.1 summarizes the details of each option. Other options are also explored in Appendix D. All together, these options explore a wide diversity of potential future force structures that are relatively cost-neutral—that is, they would command roughly similar budget levels.

Exploring Air Defense Demands

To give a sense of what each of these force structure options might provide for Taiwan in future conflicts, we examine them using three air defense vignettes. In the Air Sovereignty vignette, Taiwan faces a

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Table S.1
Force Structure Options

Option	Baseline	Mixed Force	JSF-Only Force	SAM-Dominant Force
Retrofit F-16	144	144	0	50
F-CK/IDF	127	0	0	0
Mirage 2000-5	57	0	0	0
JSF STOVL (F-35B)	0	0	57	0
AIM-120 (additional)	576	2,676	228	1,800
PAC-3 (additional)	0	4 launchers, 300 interceptors	0	13 launchers, 975 interceptors
Air defense platoons	0	21	0	40
Modernization investment estimate (billions of BY 2013 U.S. dollars) ^a	6.7	6.7	6.7	6.7
20-year cost difference (billions of BY 2013 U.S. dollars; negative numbers indicate savings)	-2.008	-0.882	-0.033	-0.480

NOTE: BY = base year. AIM-120s and PAC-3s in this table are in addition to Taiwan's existing inventory.

^a The US\$5 billion modernization investment is an estimate of new military investment in air defense capabilities over 20 years. It is derived in Chapter Two.

naval blockade, and its fighter aircraft are asked to provide air sovereignty over Taiwan and to secure a designated sea line of communication (SLOC) from air threats. This coercive use of force leads to limited air-to-air combat that is constrained both in the rate of encounters and in the objectives, with both sides seeking to limit damage. The second vignette, Disarming Strikes, is also a coercive scenario but involves much more-violent attacks on Taiwan itself, designed to eliminate major elements of Taiwan's defenses. In this vignette, Taiwan seeks to exact a price from threatening aircraft while maintaining a large fraction of its air defense capabilities in case the conflict intensifies. The third vignette, Invasion Air Defense, involves the air defense aspects of an invasion scenario. Taiwan employs its SAMs as we recommend,

to enable important defensive operations of other elements of Taiwan's military, thus creating windows of opportunity for operations by protecting SAMs from many of the potential air and missile threats they might otherwise face.

Insights from Vignettes

In the Air Sovereignty vignette, we explore the relative air-to-air capabilities of Taiwan's fighter force against the PLA's J-10, J-11A FLANKER, and the J-11B modified FLANKER in a relatively fair fight, consisting of multiple encounters of four PLA aircraft against two defenders. The vignette features Taiwan's fighters operating in pairs to protect Taiwan's airspace and SLOCs. These defenders encounter four PLA aggressors, and the vignette tests how many such incursions Taiwan can contest. The three current fighters Taiwan operates have roughly similar survivability against these threats; although the F-16 retrofit offers an improvement over Taiwan's current aircraft when it becomes fully operational, it will be less capable than the J-11B. The new JSFs offers greater survivability. We do assume differences in overall effectiveness among the aircraft, primarily because of their varying ability to handle likely PLA countermeasures when outnumbered. The JSF is the most capable of coping in dynamic multiship engagements, followed by the F-16, the Mirage, and finally the F-CK, which has the poorest ability in this regard. The aircraft's relative capability is not the only factor to note: The performance of the options is also tied to the overall number of aircraft in the force, because we are assessing how many engagements can be sustained before Taiwan is unable to contest its airspace. Against current threats, the three options with the largest fighter force structure can maintain operations for one to more than four months; however, in the future, when facing such systems as the J-11B upgrade armed with PL-15 missiles, the difference between these three options narrows. They can sustain operations for roughly two to four weeks (see Table S.2).

The Disarming Strikes vignette allows us to consider the effectiveness of SAMs against the coercive use of air and cruise missile attacks directed at Taiwan's integrated air defense system (IADS). This vignette features much more-intense and wider-ranging attacks on Taiwan's

Table S.2
Aircraft Effectiveness in 2v4 Fights

Force Structure Option	Total Number of Fighter Aircraft	Days Defense Sustained Versus Current Threats	Days Defense Sustained Versus Future Threats
Baseline	328 (F-16 retrofit, F-CK, Mirage)	62	31
Mixed Force	144 (F-16 retrofit)	36	16
JSF-Only Force	57 (JSF STOVL)	>120	33
SAM-Dominant Force	50 (F-16 retrofit)	12	5

NOTE: 2v4 is shorthand for “two aircraft versus four in each engagement.”

IADS than the Air Sovereignty vignette, which was limited to air-to-air engagements only. The level of attack on Taiwan’s air bases is so substantial that Taiwan’s fighters would either be forced to hide underground or be destroyed quickly, so, in the Disarming Strikes vignette, Taiwan defends with air defense platoons or, in the options without them, Patriots. The SAMs are used to exact a price for the attacks, rather than to defend fixed assets. Used in this way, the SAMs become much more survivable and thus are able to exact a much higher toll on PLA aircraft. The PLA attacks with ballistic and cruise missiles, as well as fighters and fighter-bombers. Taiwan seeks to shoot down attacking aircraft in retribution. If Taiwan can pick its engagements carefully, the AIM-120 missile could be quite effective. To shoot down on the order of 200 attacking aircraft, Taiwan would need five to 20 Sentinel radars and expend 600 AIM-120 missiles for this vignette. In addition, a reserve of radars and missiles that could be devoted to countering an invasion, which is the third vignette, would be prudent.

In the Invasion Air Defense vignette, we examine the challenges associated with air defense during an invasion of Taiwan using both Patriot/TK III batteries and air defense platoons, for layered defense against threat aircraft (for the options that have both layers). Here, again, we do not consider the purpose of the SAMs to be to defend fixed assets but instead to enable important defense operations by limiting the PLA air threat during those periods of operation. For instance, if

Taiwan's defense concept involves counterattacking landed PLA forces, then the air defense mission is to protect Taiwan's maneuver units from air threats while they engage in their counterattack. In addition to holding at risk fixed-wing aircraft, the air defense platoons play an important role in defending Patriot/TK III radars and disrupting PLA attack helicopters, unmanned aerial vehicles (UAVs), and airborne operations. During the windows in which Taiwan's ground forces are maneuvering, they can be attacked and disrupted by attack helicopters flying across the Taiwan Strait and by multiple rocket launchers (MRLs) and regular artillery that are cued by UAVs. Taiwan's baseline IADS lacks survivable medium-range air defenses that can attack helicopters before they get into range to fire weapons or that can attack UAVs before they get within sensor range of ground forces.

Taiwan could choose to size its force to have a capacity to cope with a sequential attack that unfolds with engagements resembling the Disarming Strikes vignette initially, followed by an invasion requiring windows of opportunity addressed in the Invasion Air Defense vignette. A sequential attack would require five to 20 Sentinel radars for the Disarming Strikes vignette, and the Invasion Air Defense vignette requires 16 to 23 more Sentinel radars to create between 12 and 18 two-hour windows, while suffering 5 or 10-percent attrition per engagement, in support of other defensive operations.⁴ Taiwan's current force of 21 Patriot/TK III radars can open 12 two-hour windows of opportunity with 50-percent attrition per engagement. Investments to increase the Patriot/TK III force could allow Taiwan to open 18 two-hour windows and meet its goals even if it suffers higher attrition.⁵ Table S.3 summarizes the radar demands. This level of radar investment would also require 1,200 Patriot/TK III interceptors and

⁴ This assumes that half of the Sentinel radars are attacked in any two-hour window, so the marginal replacement cost is 0.3 to 0.6 radars per two-hour period.

⁵ As with the Sentinel example, the marginal cost to increase the number of windows by 50 percent is comparatively small. For the Patriots, this is in part because the early windows are created by a mix of PAC-2s, PAC-3s, and TK IIIIs. By assuming that the new investment is in PAC-3s, which is a more capable system and, importantly, has more-numerous ready missiles in each battery, so six additional two-hour windows can be created with four to seven more radars.

Table S.3
Radar Needed for Sequential Attacks

Radar	Attrition per Engagement (%)	Disarming Strikes	Invasion Air Defense		
			12 Two-Hour Windows	18 Two-Hour Windows	Total
Patriot/TK III	50	0	21	25	21–25
	75	0	26	33	26–33
Sentinel	5	5	16	18	21–23
	10	20	20	23	40–43

NOTE: This shows the radar demands to shoot down 200 aircraft in the Disarming Strikes vignette and to create 12 to 18 two-hour windows of cleared airspace over Taiwan, facing 100 fighter aircraft, 25 attack helicopters, and 25 UAVs every two hours.

1,600 to 2,100 AIM-120 missiles to cope with these two vignettes sequentially.

Findings

Taiwan is unfortunately situated very near a country that continues to make military threats and has invested extensively in a wide range of capabilities that will make it very difficult for Taiwan to fly fighter aircraft in combat. Although it might be painful for leaders in Taiwan to think of a major divestment of its fighter force, the expectations about the efficacy of that force need to be curtailed. There is a substantial opportunity cost for keeping the current, large fighter force, which will limit needed SAM investment that could offer greater air defense protection in the most intense scenarios.

At current spending levels, Taiwan will spend about US\$25.3 billion on its fighter force in the next 20 years, which is a substantial fraction of its overall defense budget, but these platforms are sufficient to defend Taiwan only if the PLA applies very measured force in ways that allows Taiwan to employ its fighters. There are instances in history when a stronger power has elected to limit the use of force, so Taiwan certainly could be confronted with a situation along the lines of the

Air Sovereignty and the Disarming Strikes vignettes. However, Taiwan's policymakers will have to decide how much they want Taiwan to pay to retain fighter aircraft in light of their limitations. Fighters do have some advantages over SAMs in limited coercive scenarios (for instance, an ability to intercept aircraft farther away from Taiwan). Newer PLA fighters have surpassed the current force. If Taiwan would prefer to invest in newer and more-capable aircraft, it would need to either increase its budget or reduce the size of the fleet. Still, even a smaller, more-modern force remains vulnerable to attacks while on the ground but can offer resistance in a coercive scenario, such as the Air Sovereignty vignette, for a matter of days.

We recommend that, as Taiwan assesses its future air defense needs, it devote most of its air defense resources to investment in its SAM force. The SAM force is an enabling force; it clears airspace to allow other critical military operations. In sizing that force, it should be able to meet the demands on the SAM forces to support maneuver forces in an invasion scenario but also have the capacity to meet some air defense demands in a coercive scenario, which could be a prelude to a larger conflict and thus places an additive demand on the SAM force.

Taiwan already has some Patriot/TK III systems. These should be complemented with a shorter-range system that could provide a more cost-effective layered air defense. We have considered here a new air defense system, which we call air defense platoons, that can engage aircraft and cruise missiles using ground-launched air-to-air missiles. Such a system can rapidly engage many targets, has a deep magazine, and is built around lower-cost radars networked together that allow them to effectively engage many targets in a short amount of time. The combination of a short-range interceptor, such as a ground-launched AIM-9X, which can shoot down weapons fired at the Sentinel radar, and a longer-range ground-launched AIM-120 makes for a formidable defense when used appropriately with the more-capable and costly Patriot/TK III defenses. By proliferating the Sentinel radars at the core of the air defense platoon system, using emission-control and deception tactics, and coordinating with the longer-range defenses to seize control for a certain limited block of time, Taiwan's forces can create windows of time in which other military actions can be taken with a

greatly diminished threat of observation or attack. This is not costless to the defender, and radars will be lost, but it will not be catastrophic to the defense.

A force of 21 air defense platoons (which have 42 Sentinel radars) armed with 1,600 to 2,100 AIM-120 missiles would cost between US\$8.1 billion and US\$9.2 billion. It could protect large areas of Taiwan for defensive operations. These would benefit from further investments in Patriot/TK III systems ranging from five to 12 new batteries and 300 PAC-3 missiles. These would cost between US\$4 billion and US\$10.6 billion and would give Taiwan a capability to sequentially deal with a coercive attack, like the Disarming Strikes vignette, and an invasion. Its current planned force plus an additional 300 PAC-3 missiles would posture Taiwan's SAMs to be able to open 12 two-hour windows of opportunity. If an additional five to 12 new Patriot batteries are added, Taiwan would be postured to open either 12 windows against a force 50 percent larger or 18 two-hour windows under more-pessimistic attrition assumptions with the larger force of 12 new batteries.

Without an increase in defense spending, Taiwan will need to substantially reduce the size of its fighter force in order to afford these new SAM capabilities. If Taiwan divested its F-CK and Mirage force, it could afford to fully invest in the air defense platoons and still have resources to increase its Patriot force. If Taiwan wanted to fully invest in all the SAM capabilities explored in Table S.4, it would need to reduce the F-16 force as well.

Taiwan's air defense investments also need to be linked with modernization steps taken across other defense missions. Taiwan's fighter aircraft are suited to a limited role in coercive scenarios involving a fairly low level of force. Taiwan will have to decide how much it wants to spend to retain such a capability. To continue to provide a credible deterrent and be seen as having the potential to contest its own airspace, Taiwan needs to invest in and invigorate its SAM force. These should get priority over fighters. The SAM investments are enabling capabilities: They clear the airspace of threats so that other military capabilities can perform critical functions, such as counterattacking landed forces. So their exact size needs to be linked with the opera-

Table S.4
Surface-to-Air Missile Force Sizing and Costs

SAM	New Interceptor Missiles	Cost (billions of BY 2013 US\$)	Capabilities
21 air defense platoons	1,600–2,100	8,083–9,189	Five platoons devoted to countercoercion, 16 devoted to layered defense with Patriot to counter invasion, 5% attrition
Current Patriot/TK III	0	0	12 two-hour windows, 50% attrition
5 Patriots	300	4,002	12 two-hour windows with 75% attrition or, with 50% attrition, 18 two-hour windows or 50% sortie surge of PLA fighters
12 Patriots	300	10,686	18 two-hour windows, or 50% sortie surge of PLA fighters, with 75% attrition

NOTE: This assumes a current inventory of 21 Patriot/TK III batteries and 1,500 Patriot/TK III interceptors. The table indicates the additional Patriot batteries and interceptor missiles to achieve the capability goals of the final column.

tions they are intended to support. Table S.4 indicates what different SAM investments might provide. Once SAMs are acquired, Taiwan then must refine survivable concepts of operations for those forces and train highly competent forces to operate in stressing warfighting environments.

Taiwan's air defense problem is perhaps the most difficult in the world, but Taiwan still retains choices and can make meaningful investments to strengthen its air defense capabilities and get the most out of its air defense investments.

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Abbreviations

AAM	air-to-air missile
AESA	active electronically scanned array
ALCM	air-launched cruise missile
AMRAAM	Advanced Medium-Range Air-to-Air Missile
ARM	antiradiation missile
AWACS	airborne warning and control system
BVR	beyond visual range
BY	base year
CAP	combat air patrol
CEP	circular error probable
DSCA	Defense Security Cooperation Agency
EA	electronic attack
EO	electro-optical
EW	electronic warfare
FDOA	frequency difference of arrival
FMS	Foreign Military Sales
GCI	ground-controlled intercept

GDP	gross domestic product
IADS	integrated air defense system
IBCS	Integrated Air and Missile Defense Battle Command System
IDF	Indigenous Defense Fighter
IOC	initial operational capability
IR	infrared
IRST	infrared search and track
ISR	intelligence, surveillance, and reconnaissance
JSF	Joint Strike Fighter
MANPADS	man-portable air defense system
MML	multimissile launcher
MRBM	medium-range ballistic missile
MRL	multiple rocket launcher
MSE	Missile Segment Enhancement
NATO	North Atlantic Treaty Organization
O&S	operations and support
PAUC	program acquisition unit cost
PGM	precision-guided munition
Phit	probability of hit
Pk	probability of kill
Pk/h	probability of kill given a hit
PLA	People's Liberation Army
PLAAF	People's Liberation Army Air Force

PRC	People's Republic of China
RCS	radar cross-section
RF	radio frequency
ROC	Republic of China
ROCAF	Republic of China Air Force
SAM	surface-to-air missile
SAR	Selected Acquisition Report
SEAD	suppression of enemy air defense
SHORAD	short-range air defense
SLOC	sea line of communication
SRBM	short-range ballistic missile
STOVL	short takeoff and vertical landing
STT	single-target track
TDOA	time difference of arrival
UAV	unmanned air vehicle
UCAV	unmanned combat aerial vehicle
UGF	underground facility
USMC	U.S. Marine Corps
VTOL	vertical takeoff and landing

Introduction and the Threat Environment

Taiwan has long sought to keep a qualitative edge over the forces of its large neighbor, but two decades of sustained investments by the People's Republic of China (PRC) in a broad range of military capabilities are leaving Taiwan's air defense behind. China has invested in highly accurate long-range surface-to-air missiles (SAMs), along with accurate ballistic and cruise missiles that can hold Taiwan's aircraft on the ground at risk. This creates a uniquely vexing airpower challenge for Taiwan. This is not to say that Taiwan cannot achieve some deterrent goals with its air and air defense forces, but it does suggest that all of Taiwan's military investments should be unflinchingly scrutinized with regard to their value across a range of potential future confrontations and conflicts. This report seeks to provide such scrutiny to the air defense problem that Taiwan faces and to assess different investment options that Taiwan might pursue.

To control or, failing control, contest the airspace above and immediately around its territory, Taiwan fields fighter aircraft and SAM forces; the supporting intelligence, surveillance, and reconnaissance (ISR) and radar systems; and robust tactical- and operational-level communications, command, and control systems. Challenges to that control currently include manned and unmanned aircraft, as well as ballistic and cruise missiles. The quality and quantity of the mainland threats to Taiwan's air defenses have grown to the point that, in a future conflict, Taiwan's forces could quickly become overwhelmed.

The Air Threat

Several reports have described China's military investments and capability growth over the past quarter-century and documented consistent expansion of the PRC's capabilities.¹ The growth in the PRC's capabilities has been impressive and sustained. Particularly in the beginning of this period of military growth, investments appeared optimized for contingencies involving Taiwan. Examples include the numerous short-range ballistic missiles (SRBMs) that have threatened Taiwan for years and were used coercively in 1995 and 1996. Initially, the accuracy of these systems was fairly poor, but now they are quite accurate. Although the early investments concentrated heavily on building up a threatening missile inventory, in more-recent years, the PLA has invested in a wider range of sophisticated systems to present a much more diversified threat. These include fielding new, sophisticated fighter aircraft and fighter-bombers. Highly accurate air-to-ground weapons, sophisticated electronic warfare (EW) capabilities, and a nascent aerial refueling capacity enhance these capabilities. In addition, the PLA has invested in a diversity of ISR platforms, including space-based and ground-based systems, as well as manned and unmanned aerial platforms. The PRC relied initially on Russian technology but is now able to produce many systems on its own. China has also procured from Israel and developed its own loitering antiradiation unmanned aerial vehicles (UAVs), which are used to attack emitting systems, such as radars.

¹ Examples that cover operational aspects of those investments include the annual U.S. Department of Defense report on the People's Liberation Army (PLA) (Office of the Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China 2014*, Washington, D.C., April 24, 2014); Roger Cliff, John F. Fei, Jeff Hagen, Elizabeth Hague, Eric Heginbotham, and John Stillion, *Shaking the Heavens and Splitting the Earth: Chinese Air Force Employment Concepts in the 21st Century*, Santa Monica, Calif.: RAND Corporation, MG-915-AF, 2011; National Air and Space Intelligence Center, *Ballistic and Cruise Missile Threat*, Wright-Patterson Air Force Base, Ohio, NASIC-1031-0985-09, April 2009, p. 15; Michael S. Chase and Andrew S. Erickson, "The Conventional Missile Capabilities of China's Second Artillery Force: Cornerstone of Deterrence and Warfighting," *Asian Security*, Vol. 8, No. 2, 2012, pp. 115–137; Michael O'Hanlon, "Why China Cannot Conquer Taiwan," *International Security*, Vol. 25, No. 2, 2000, pp. 51–86.

Taiwan's proximity to China, coupled with the large numbers and diversity of threat systems, creates an extremely complex and challenging air defense problem. Although the extreme challenge has been identified for several years now, the response from Taiwan has been less than energetic.²

Taiwan's defense budget has grown in the past decade, particularly in the early part of that time period, but has hovered at a little more than NT\$320 billion (about US\$10 billion) for the past several years. At the same time, the size of the force has shrunk. In the mid-1990s, when the PLA launched missiles over Taiwan, Taiwan had a military force of 452,000; it now has less than half that force and might, in the future, retain only 170,000. Taiwan has also had difficulties in transitioning to an all-volunteer force.³ The switch to an all-volunteer force is commendable because it will yield more-professional, better forces; however, it will necessitate higher per capita costs. In this period, Taiwan's acquisition of U.S. defense systems has also been rather modest relative to the PLA's investments. The most notable additions for Taiwan have been additional Patriot units, SM-2 Block IIIA maritime air defense missiles, retrofitting their F-16s, AIM-120 air-to-air missiles, P-3C maritime patrol aircraft, Osprey mine-hunting ships, sub-launched harpoon missiles, AH-64D Apache Longbow attack helicopters, and Javelin antitank missiles.⁴ Although some of these systems will certainly provide some useful capabilities, it is hard to find clear examples of Taiwan responding comprehensively to the changing circumstances brought about by China's investments. In many cases, a rethinking of Taiwan's defense concepts is in order.

² David A. Shlapak, David T. Orletsky, Toy I. Reid, Murray Scot Tanner, and Barry Wilson, *A Question of Balance: Political Context and Military Aspects of the China–Taiwan Dispute*, Santa Monica, Calif.: RAND Corporation, MG-888-SRF, 2009.

³ Taiwan's National Defense Report for 2013 states the current force is 215,000 (Ministry of Defense of the Republic of China, *National Defense Report: 2013*, October 2013b, p. 130). More recently, there have been signals that total end strength will fall to between 190,000 and 170,000 by 2019 (J. Michael Cole, "Is Taiwan's Military Becoming Too Small to Fight?" *Diplomat*, March 19, 2014).

⁴ Shirley A. Kan, *Taiwan: Major U.S. Arms Sales Since 1990*, Washington, D.C.: Congressional Research Service, CRS RL30957, June 13, 2014.

Surface-to-Air Missiles and Ballistic Missile Systems

Taiwan currently has 31 long- and medium-range SAM batteries. The existing set of Patriot, TK I/II systems, and I-HAWK is built around the rather traditional approach of using SAMs to defend higher-value targets. Taiwan's air defenses are in a transition period as Taiwan upgrades its existing three Patriot batteries to the PAC-3 standard, fields an additional six Patriot PAC-3 batteries recently purchased, and begins to replace its I-HAWK systems with the new TK III.⁵ In this report, we consider Taiwan's air defense system as it is expected to look after this transition is complete (Table 1.1).

The Patriot is a highly capable system that has evolved from a strictly air defense role against air-breathing targets,⁶ such as cruise missiles and manned aircraft, to one that many see as focused on defense against SRBMs. The TK I/II/III system is Taiwan's indigenous SAM system; the newest of these, the TK III, replicates some of the function-

Table 1.1
Taiwan's Ground-Based Air Defenses

Name	Number of Batteries	Battery Missile Capacity	Mobility	Intercept SRBM
Patriot	9	40	Movable in ~60 minutes	Yes
TK I/II	6	40–60	Fixed	No
TK III	12	24	Movable in ~30 minutes	Yes

SOURCES: "Taiwan," *Jane's Land-Based Air Defence*, April 10, 2012; "AN/MPQ-53/-65 Guidance Radar," *Jane's Radar and Electronic Warfare Systems*, July 25, 2014; "MIM-104 Patriot," *Jane's Land-Based Air Defence*, March 18, 2014; "Tien Kung 1/2/3 (Sky Bow)," *Jane's Strategic Weapon Systems*, July 30, 2013; "Tien Kung I," *Land Warfare Platforms: Artillery and Air Defence*, November 19, 2013; "Tien Kung II," *Land Warfare Platforms: Artillery and Air Defence*, November 19, 2013.

NOTE: Taiwan currently has three Patriot batteries with an additional six on order. The TK III missile is in early production, with 12 batteries expected to be fielded.

⁵ Wendell Minnick, "Taiwan Retires Hawk Missiles," *Defense News*, September 15, 2014. A battery is a functional unit of launchers, radars, and command elements.

⁶ *Air breathing* refers to the fact that these are within atmosphere, as opposed to missiles that enter space.

ability of the Patriot system and is expected to be allocated much in the same way, to defense of key installations and large formations of forces. The I-HAWK system is a medium-range air defense system designed to deal with low- and medium-altitude threats. I-HAWKs are fairly old systems and are expected to be replaced by the TK III.

One of the key attributes of Taiwan's current set of SAMs is that they are deployed very much in a classical air and missile defense role that requires them to be active in order to defend installations under their protection. This approach inevitably will trade away survivability of the SAM sites in favor of the installations they are protecting. In the face of very large attacks from an opponent with a numerically superior force, such approaches to defense increase the costs of attacks but do not greatly increase the survivability of the targets under their protection.

The PRC's missile strike force is evolving quickly. It currently consists of approximately 1,100 to 1,300 ballistic missiles and hundreds of cruise missiles and long-range multiple rocket launchers (MRLs) capable of reaching Taiwan.⁷ Table 1.2 provides estimates of several missile classes threatening Taiwan.

China's newer ballistic and cruise missiles have circular errors probable (CEPs) of less than 50 m, with older variants being replaced every year.⁸ Because the lethal radius of the cluster-munition warheads on the ballistic missiles is greater than 50 m,⁹ a single missile arriving on target will have a high probability of damaging a SAM (likely its radar or other emitting element).

Fighter Aircraft Fleets

China has also invested considerably in its fighter and fighter-bomber forces in the past decade, though here the balance in combat capability is closer to parity. Going forward, China will enjoy numerical and qualitative superiority over Taiwan's fighter aircraft. The most likely

⁷ "Strategic Weapons Systems," *Jane's Sentinel Security Assessment: China and Northeast Asia*, May 22, 2014.

⁸ "Strategic Weapons Systems," 2014.

⁹ Shlapak et al., 2009, p. 34.

Table 1.2
People's Republic of China Missiles Threatening Taiwan's Air
Defenses

Name	Type	Number of Missiles
DF-11	SRBM	700–800
DF-15	SRBM or medium-range ballistic missile	300–400
DF-21	Medium-range ballistic missile	75–100
AR-3	MRL	
DH-10	Ground-launched cruise missile	Up to 500
YJ-62	ALCM	
KD-88	ALCM	

SOURCES: "Strategic Weapons Systems," 2014; Dennis M. Gormley, Andrew S. Erickson, and Jingdong Yuan, *A Low-Visibility Force Multiplier: Assessing China's Cruise Missile Ambitions*, Washington, D.C.: National Defense University, 2014.

NOTE: ALCM = air-launched cruise missile.

fighters to be deployed in a cross-Strait scenario against Taiwan will be made up primarily of fourth-generation fighters, such as the J-10, J-11A (Russian Su-27 FLANKER), Russian Su-30MKK/MK2, and China's indigenously produced upgraded FLANKER, the J-11B. Other fighters could also be used, such as the venerable J-8 operated by the PLA Naval Air Force; however, we consider this to be less likely given the aircraft's reduced overall combat capability as a third-generation fighter. A description of China's two most capable fourth-generation fighters, the J-10 and J-11B, is provided next.

The J-10 (pictured in Figure 1.1) is a single-engine, multirole fighter that first entered service in 2005. The aircraft is equipped with modern, indigenously produced avionics and weapons that can engage a variety of both air and ground targets in complex environments, especially when the pilot is aided by ground or airborne controllers using secure voice and data links. The heart of the avionic suite is the KLJ-3/7 multimode fire control radar, which can detect and track conventional targets in excess of 50 nm. Passive engagements are possible when using the midwave-infrared search-and-track system.

Figure 1.1
J-10 Fighter



SOURCE: J-10b Photo courtesy of 天劍2.

RAND RR1051-1.1

A state-of-the-art defensive avionic suite built around the KJ-8602 radar warning receiver and KG-300 jammer provides a measure of increased survivability against Western-designed radars. The J-10 is capable of employing a variety of Chinese-developed weapons in air-to-air and air-to-ground missions. The medium-range PL-12 air-to-air missile (AAM) is by far the weapon of choice for beyond-visual-range (BVR) combat, with the short-range infrared (IR)-guided PL-8B and guns being most useful during close-in combat. Newer J-10 variants can employ the YJ-91 antiradiation missile (ARM), as well as small numbers of guided bombs for air-to-ground missions. The aircraft's relatively small size, together with presumed use of radar signature treatments (radar-absorbent material and inlet design), is believed to put J-10 in the same class as other small radar cross-section (RCS)-treated aircraft.

China's most capable fourth-generation fighter is arguably the J-11B (pictured in Figure 1.2). Although similar in appearance to the

Figure 1.2
J-11B Fighter



SOURCE: DoD photo as published in Kopp, 2012.

RAND RR1051-1.2

Russian Su-27/Su-30 family of FLANKER aircraft, the indigenously developed J-11B has significant combat capabilities compared with the Russian version, which were likely leveraged and improved upon from the J-10 program. The aircraft was originally powered by Russian-designed engines (but manufactured in China); newer versions are probably now powered by China's indigenous WS-10 engine.

Like all FLANKER aircraft, though, the J-11B can carry up to ten AAMs (six medium-range PL-12 plus four short-range PL-8 missiles) and engage enemy aircraft at longer ranges than the smaller J-10 can. An upgraded version of the J-11B called J-16 is reportedly being developed, which, when fielded, might feature an active electronically scanned array (AESA) fire control radar and longer-range PL-15 AAM. The primary mission of the J-11B/J-16 is air superiority.

As with the J-10, a modern, purpose-built avionic suite equips the J-11B/J-16 to engage and defend against a variety of air targets. The large size of the aircraft allows for a more capable fire control radar that can detect and track targets in excess of 80 nm. A complementary

infrared search-and-track sensor can be used to detect and engage targets in a passive mode using IR signatures. Defensive aids are based on the same KJ-8602 and KG-300 family of radar warning receivers and jammers that are found on the J-10.

The PRC's fourth-generation fighters are summarized in Table 1.3.

Taiwan's future force will have less than three-fifths of the fourth-generation fighters the PLA fields. Going forward, Taiwan's air force is planned to consist of about 325 operational fighters at ten military air bases (Table 1.4).¹⁰

The F-CK was built indigenously with design help from U.S. defense firms. It was heavily influenced by the F-16 design and became operational in 1994. Taiwan received about two wings of F-16A/Bs from the United States between 1997 and 1999. They can be armed from a small inventory of AIM-120 AAMs, as well as shorter-range Sidewinder AIM-9 missiles. In that same time period, Taiwan received

Table 1.3
People's Republic of China's Fourth-Generation Fighters

Fighter	Number	Mission	Weapons	IOC
J-10A	264+	Multirole	PL-12, PL-8B, YJ-91 (limited)	2005
J-11A (Su-27SK)	95	Air superiority	AA-10, AA-11, AA-12	1992
J-11B	158+	Air superiority	PL-12, PL-8B	2007
Su-30MKK/MK2	100	Multirole	AA-10, AA-11, AA-12, YJ-91, AS-17b, AS-14, AS-18	2000
J-11B upgrade (J-16)	Unknown	Air superiority	PL-15, PL-8B, PL-10, KD-88	2020 (estimated)

SOURCE: "Weapons/Systems/Platforms/Aircraft—Fighter," *Military Periscope*, undated; Hui Tong, "Attack Aircraft I," *Chinese Military Aviation*, last updated April 19, 2015a; Hui Tong, "Fighters II," *Chinese Military Aviation*, last updated April 24, 2015b.

NOTE: IOC = initial operational capability.

¹⁰ Taiwan's F-5 fighters are nearing obsolescence and will soon be out of the inventory and therefore are not considered in the rest of this analysis.

Table 1.4
Taiwan's Fighters

Fighter	Number	Mission	Weapons	IOC
F-16	144	Multirole	AIM-120, AIM-9	1996
Mirage 2000-5	57	Multirole	MICA, Magic	1997
F-CK	127	Multirole	TC-2, TC-1	1993

SOURCE: "Air Force," *Jane's Sentinel Security Assessment: China and Northeast Asia*, May 29, 2014.

Mirage 2000-5s from France, along with MICA medium-range and Magic short-range AAMs.¹¹

All of Taiwan's current fighters are capable of engaging enemy aircraft at BVR under a variety of engagement geometries and flight conditions up to supersonic speeds. All are equipped with modern, all-aspect, pulse-Doppler lookup and lookdown fire control radars that can provide midcourse guidance to AIM-120, MICA, and TC-2 active radar missiles. Once these missiles acquire their intended target, the pilot is free to disengage from the fight in order to increase his or her chances of surviving against incoming missiles. Although similar in type, AIM-120 has superior range and seeker performance to MICA and TC-2 missiles, and it is also believed to be more resilient to the effects from radio-frequency (RF) countermeasures and ground clutter than these other missiles.

If required, short-range IR missiles and guns allow for combat in visual range, though such close combat would likely be rare given radar and missile ranges. The capabilities of Taiwan's current AIM-9, Magic, and TC-1 IR missiles are roughly equivalent to each other in relatively benign combat settings; differences are most pronounced when IR countermeasures (flares) are used. However, pilot dogfighting skills, tactics, and training with helmet-mounted sights (where applicable), not the relative performance of these fourth-generation fighters, will be the deciding factor during close-in combat.

¹¹ Bernard D. Cole, *Taiwan's Security: History and Prospects*, New York: Routledge, 2006, p. 108.

Next to weapons and tactics, defensive avionics and supporting electronic countermeasures can provide a measure of improved survivability against an adversary. The effectiveness of jamming, though, is tightly governed by the particulars of the jammer and victim RF systems and the extent to which a country can regularly collect, exploit, and update countermeasure suites with new data or algorithms. For comparison purposes, note that we believe that Taiwan's oldest fighters (F-16A/B and F-CK) are probably more vulnerable to PLA electronic countermeasures than the more advanced Mirage 2000-5 with the integrated countermeasure system suite, but, if the complete retrofit program is implemented, the F-16s will offer more capability than the Mirage. Modern systems, such as the integrated countermeasure system, increase aircraft survivability by denying or degrading enemy radar detection and tracks that, in turn, reduce missile firing ranges and probability of successfully guiding to the target during missile flyout.

For force-sizing purposes, fighter range, speed, and loiter performance are roughly the same for the F-16, Mirage, and F-CK. If available, external fuel tanks can be added to increase combat air patrol (CAP) time on station for three to four hours for short-range missions.

Attacking Taiwan's Integrated Air Defense Systems: The Feasibility of a Knockout Punch

The PLA has been turning up the temperature on Taiwan's fighter force and now has the means to destroy it (or force it into underground storage). Taiwan's SAMs could face a similar fate if they are used to defend fixed assets (but later we describe a more promising alternative). In a future conflict, China could employ its military in numerous ways. In this section, we describe an attack at the extreme end of the force spectrum that China could employ against Taiwan, in which China seeks to eviscerate Taiwan's current air defenses. (Later in this report, we explore three vignettes that span the range of the force spectrum China could employ.)

Although China has many options and forces, a straightforward strategy to cripple air defenses would be to attack each part of Taiwan's air defenses in turn in a way that isolates it from the others. These attacks might unfold as follows:

1. Overwhelm the ballistic missile defenses (Patriot/TK III) with large numbers of ballistic missiles and rockets, killing their engagement radars.
2. Attack fixed or located SAMs (TK I/II) with ballistic missiles, rockets, and cruise missiles.
3. Crater air-base runways with ballistic missiles to prevent reinforcing aircraft from taking off.
4. Attack aircraft on the ground using large fixed-wing aircraft strikes.

China's ballistic missile force poses a unique threat to the large and highly capable radars that direct Taiwan's long-range SAMs. If used to defend fixed assets, SAMs that can intercept ballistic missiles, such as the Patriot, would normally be in place ready to defend in a crisis situation. This, however, leaves them vulnerable to becoming overwhelmed by a sufficiently large attack. China has built up its missile force to the point at which it can overwhelm SAMs used in this way.

The SAMs protecting Taiwan, like all radar-guided missile defenses, have limitations tied to radar resources and processing that limits their maximum number of simultaneous engagements. The precise numbers and limitations of systems are highly dependent on the exact structure of the attack (e.g., time, number of objects being engaged, countermeasures). The Patriot, for example, can control a maximum of nine PAC-3 interceptors in the final moments of engagement.¹² The Patriot was designed to intercept SRBMs. Although the PAC-3 missile has increased the altitude at which it can engage and therefore the time it has to make engagements, longer-range and therefore faster ballistic missiles, such as the DF-15 and DF-21, greatly reduce that time. The

¹² "MIM-104 Patriot," 2014.

warheads on these missiles also have some ability to maneuver in order to increase their accuracy, which is likely to make their interception more difficult.¹³ Further penetration aids, such as warhead decoys or the suppression of the Patriot radar through airborne jammers, would also reduce the Patriot's capability. Depending on how many interceptors the Patriot is able to launch at each incoming ballistic missile and on the probability that an interceptor will kill the missile, it is plausible to assume that between five and 15 ballistic missiles simultaneously arriving at the Patriot radar will overwhelm its self-defense capability and kill it. Table 1.5 shows the total missiles required with different assumptions of the number of simultaneously arriving missiles needed to overwhelm Taiwan's nine Patriot and 12 TK III batteries. Even the most conservative assumption is well within the PLA's ballistic missile inventory. Many of the air defense batteries would also be in range of the AR-3 MRLs,¹⁴ and several that are on islands in the Strait are in range of even shorter-range systems.¹⁵

Once Taiwan's ballistic missile defenses have been disabled, the remaining fixed SAMs can be attacked. Taiwan's fixed TK I/II missiles are reported to be housed in hardened vertical silos in the ground¹⁶ and would be difficult to attack with ballistic or cruise missiles. However, the radars for these systems must still be exposed in order to function. If the radars are in the open, they can be attacked with ballistic missiles armed with cluster munitions. If they are housed in hardened bunkers,

¹³ Michael D. Swaine and Loren H. Runyon, *Ballistic Missiles and Missile Defense in Asia*, Seattle, Wash.: National Bureau of Asian Research Analysis, June 2002., p. 15.

¹⁴ The AR-3 MRL is a PLA-owned system that fires guided rockets of a variety of calibers and ranges. The largest is a 370-mm rocket with a 220-km range that is fired in volleys of eight rockets. Fired from the mainland coast, these rockets can cover all of the urban areas of northern Taiwan and the western plain down to Tainan. Warheads include cluster and fuel air explosives. The inventory of these rockets is not known, but MRL rockets are generally less expensive than ballistic missiles and are purchased in larger quantities.

¹⁵ Even if China is not able to coordinate the attacks closely enough in time to overwhelm the Patriot, intercepting ten or more ballistic missiles equipped with a range of possible countermeasures could exhaust the Patriot's ready PAC-3 missiles, making it vulnerable to a follow-on attack.

¹⁶ "Tien Kung 1/2/3," 2014.

Table 1.5
Saturating Taiwan's Ground-Based Defenses

Number of Simultaneously Arriving Missiles at Each Patriot/TK III	Total Missiles Needed ^a
5	124
10	247
15	370

SOURCE: Shlapak et al., 2009, p. 40.

^a Assumes an 85-percent missile reliability.

they can be attacked with cruise missiles flying outside their fixed arcs of coverage.

The completion of the attacks on the long-range SAMs would dramatically decrease the danger to any PLA aircraft operating over Taiwan, which could fly at a higher altitude than the remaining short-range SAMs and air defense guns could reach. This would enable an efficient attack on Taiwan's air bases following ballistic missile attacks to cut the runways and trap aircraft that are not already in the air.

Given Taiwan's proximity to the mainland, its fighter forces are vulnerable to attacks while on the ground. For example, in considering attacks to cut runways, U.S. planning documents suggest that fighters need a runway surface of $5,000 \times 50$ ft. to take off and land.¹⁷ Taiwan's ten military air bases have 12 runways from 8,000 to 12,000 ft. long and 150 ft. wide. Each also has one or more taxiways, which would allow limited air operations. Our RAND colleagues estimate that a typical ballistic missile with a 500-kg payload and a 40-m CEP, within the reported accuracy estimates for the DF-11A and the DF-15A and B, would have an approximately 25-percent chance of cutting a 150 ft.-wide runway.¹⁸

¹⁷ Secretary of the Air Force, *Rapid Runway Repair Operations*, Air Force Pamphlet 10-219, Vol. 4, April 1, 1997.

¹⁸ Shlapak et al., 2009, Figure 3.4, p. 41.

In all, 18 cuts¹⁹ would need to be made to runways and 12 cuts²⁰ to taxiways to halt fighter operations until repairs were made. These cuts would close the air bases until damage was assessed and repairs made. Repairing one cut point could take at least four hours for a practiced and well-equipped repair team.²¹ Repair operations could be hindered or completely stopped if the PRC were able to observe the repairs and attack the teams on the runways. The repair teams would have, at best, minimal warning of a ballistic missile launch. Additional ballistic missiles and MRL rockets with cluster warheads would be used against aircraft parking areas and would leave unexploded ordnance that would need to be cleared. In addition, with most of Taiwan's high-altitude SAMs destroyed and air-base operations disrupted, PRC fighters would have a large numerical advantage in the air and could drop bombs on air bases quickly after the initial ballistic missile attacks on runways. Having additional Taiwan fighters on alert to launch on (very) short warning, as well as dispersed to highway strips, would get additional fighters into the air, but this cannot overcome the PRC's nearly two-to-one advantage in fighters in the theater. As we show later, Taiwan's fighters do not have a combat advantage against future PRC fighters and, in some cases, are at a significant disadvantage. The PRC can afford to lose fighters to clear the air of Taiwan's fighters if it can then do significant damage to Taiwan's air bases and fighters on the ground.

A key consideration in estimating how consequential such a threat might be is to ascertain the attacker's capacity to conduct such attacks. What fraction of the attacking inventory might be required to execute the sequence of attacks described above? If it requires a large fraction of the PLA inventory, Taiwan might feel more secure. To calculate the number of missiles required, we describe some limitations that the attacking and defending systems have, and, based on some assumptions, we provide a rough estimate of the interactions.

¹⁹ Shlapak et al., 2009, p. 42.

²⁰ Examination using Google Earth.

²¹ Secretary of the Air Force, *Airfield Damage Repair Operations*, Air Force Pamphlet 10-219, Vol. 4, May 28, 2008; certified current May 27, 2011, p. 82.

The PRC would have a variety of means to observe the effect of the missiles, so it could adopt a firing doctrine of shooting three missiles at each cut point (for an approximately 70-percent chance of a successful cut) and then quickly reshooting where needed. Playing this strategy out completely results in all cuts completed after four cycles, using a total of 155 missiles (assuming a 40-m CEP), which is well within the PRC's available ballistic missile inventory.²² This could give China the capacity to cut all the runways at Taiwan's established air bases using SRBMs. This number would likely be lower because some of these air bases would be empty, with their fighters having been moved to the underground facilities (UGFs), and because four of these air bases are within range of the AR-3 MRL system. Table 1.6 shows the total number of ballistic missiles needed given different missile accuracies.

The attacks on runways could be followed by fixed-wing aircraft using precision-guided munitions (PGMs) to kill aircraft that are on the ground, either in shelters or in the open. Approximately 200 shelters at the air bases have no UGFs, but these shelters are not indestructible. If they are allowed to operate unchallenged, the PLA Air Force's (PLAAF's) 100 Su-30MKKs could deliver more than 600 PGMs by themselves.²³ Given China's inventory of missiles and aircraft, this attack could destroy any aircraft outside of Taiwan's underground shelters and pin those inside. Even if Taiwan were to try to protect and disperse aircraft, some limitations prevent this from being a clearly effective solution. Even if fighters were to substantially shorten the minimum operating surface needed for takeoff and landing through such techniques as partial fuel loads and landing arresting gear, the number of missiles needed is well within the PRC's inventory. Halving the minimum operating surface needed to 2,500 feet would approxi-

²² The actual sequence is three missiles fired at each of 30 cut points with an 85-percent reliability and a 69-percent probability of a successful cut. This leaves an expected value of 12.4 cuts needed. Another three missiles are fired at these, leaving 5.1 cuts needed. Then, four missiles are fired at these, with an 80-percent probability of a successful cut, leaving 1.6 remaining, and a final round leaves 0.5 cuts. In actuality, the total number of missiles would be lower than is stated because an unsuccessful cut would still likely do some damage to the runway, and reattacks could be done with fewer missiles.

²³ "Sukhoi Su-30M," *Jane's All the World's Aircraft*, February 4, 2014.

Table 1.6
Total Ballistic Missiles Needed to Close
Taiwan Air Bases

Missile CEP (m)	Total Missiles Required
40	155
25	105
5	41

mately double the required missiles, ranging from 82 to 310 depending on their accuracy.

These calculations are illustrative and do not account for the presence of active missile defenses, which could have been destroyed in the early strike phase described above. Taiwan currently has nine Patriot batteries. Even if the PRC does not follow the sequencing we have postulated, but instead attacks air bases from the beginning, allowing Taiwan to defend those air bases with its entire PAC-3 defenses—a highly unlikely PAC-3 deployment decision—those systems could not long defend the bases because Taiwan currently has fewer than 500 interceptors, compared with the PRC’s 1,000 to 1,200 SRBMs.

Taiwan could opt to conserve some of its fighters. It has an air base, Hualien, connected to a shelter tunneled into a mountain that is large enough to house 200 aircraft. Another smaller second facility, Taitung, also has been reported.²⁴ The aircraft might remain safe while they are inside such facilities, but they will not be able to generate sustained combat operations while stored there. Taiwan’s underground shelters are vulnerable to the same runway and taxiway cutting effects as are the other bases; although the aircraft at these shelters would be protected, they would not be able to take off. Further, the shelter doors

²⁴ The larger of the two shelters is called Jiashan (also spelled Chashan), an aircraft sanctuary tunneled into a mountain next to Hualien air base, while a smaller shelter is located at the Taitung air base (Wendell Minnick, “Taiwan’s Hidden Base Will Safeguard Aircraft,” *Defense News*, May 3, 2010). See also Ming-Yen Tsai, “Air Base Defense: Taiwan’s Defensive Responses to China’s Missile Threat,” in Martin Edmonds and Michael M. Tsai, eds., *Taiwan’s Security and Air Power: Taiwan’s Defense Against the Air Threat from Mainland China*, New York: RoutledgeCurzon, 2004, pp. 140–152, p. 148.

can be attacked by cruise missiles and later by aircraft-delivered PGMs, damaging or blocking them with rubble. Repairs or clearing would be extremely difficult while under constant air attack. If they are able to launch despite all of these potential impediments, the large inventory of adversary combat aircraft would allow the PLA to comfortably monitor that facility and, at the first sign of preparations to bring aircraft into a launching area, to devote a variety of strike systems to the attack. On the slight chance that an aircraft could get off the ground, it is likely to face attack before it can reach altitude or combat speeds.

Taiwan has publicized its ability to use select highway locations to recover and launch fighter aircraft. With more than 200 fighters in Taiwan's UGFs, only 100 or so fighters would remain on the air bases. Some of the fighters could attempt to operate from highway air-strips or other unconventional locations; however, such operations have complex logistical requirements and could become very vulnerable to attack themselves if the PRC has the situational awareness to track where these aircraft land and launch strikes on their locations before they relaunch. For example, PRC airborne warning and control aircraft could track the aircraft to their landing sites and high-altitude UAVs spot them on the ground, delivering coordinates to waiting aircraft or ballistic missile units. If the PLA could identify landing locations of aircraft when they land, it would be very difficult to turn the aircraft before an attack came. Even if Taiwan had some initial success with nontraditional operating locations, such operations could not be sustained for numerous sortie turns in the face of such threats.

Once the PLAAF has completed its first set of missions, focused on air-to-air combat, cutting Taiwan air-base runways, and destroying fighters on the ground, most of the remaining PLAAF sorties can be devoted to ground attack. Decreasing the effectiveness of the air-to-ground sorties over time will be critical to the success of any effective defense of Taiwan. Taiwan's integrated air defense system (IADS) will need to last beyond the initial onslaught to contest Taiwan's airspace and decrease PLAAF effectiveness.

Implications for Future Air Defenses

Contesting the air with fighter aircraft based on Taiwan appears infeasible if China goes all out in its attacks on the fighter force. Taiwan's current ground-based air defenses using today's operational concepts will certainly exact a toll on PLA air operations, but they do not have the capacity to exact a high enough toll, or to protect the air bases enough, to keep them operational for more than a few hours of concerted attacks. How long the ground-based air defense can survive will depend not only on the number of batteries but also on how they are employed. Taiwan needs a new air defense concept, one designed for the threats it faces.

Some hints at effective future air defense strategies against stronger powers can be drawn from the air war over Serbia. During that conflict, Serb aircraft rarely flew against North Atlantic Treaty Organization (NATO) forces. The Serbs also adopted a strategy to conserve ground-based SAMs, challenging NATO aerial forces only under favorable conditions. Still, this limited use of force, combined with the fact that Serb SAMs remained a force in being, imposed flight limitations on NATO air operations. Although Serbia operated older SAM systems (SA-2s, SA-3s, and SA-6Bs), they did down two aircraft.²⁵ Had these been more modern, NATO would have had to operate with even more caution or face greater losses. As one RAND analysis of the war summarized, "Operation Allied Force demonstrated that U.S. air forces could not inflict much damage on fielded forces if those forces dispersed and employed cover and concealment techniques in rugged terrain."²⁶ The implication for Taiwan is that a ground-based air defense can influence the operations of a larger and more sophisticated force, but also that the concept for operating it should consider both the survivability of the SAMs and their lethality against enemy aircraft.

²⁵ Martin Andrew, *Revisiting Lessons of Operation Allied Force*, Air Power Australia Analysis 2009-04, June 14, 2009.

²⁶ Bruce R. Nardulli, Walter L. Perry, Bruce R. Pirnie, John Gordon IV, and John G. McGinn, *Disjointed War: Military Operations in Kosovo, 1999*, Santa Monica, Calif.: RAND Corporation, MR-1406-A, 2002, p. 48.

There are several possible approaches to using the SAM forces in a manner that would be better suited to meeting the challenges that Taiwan faces. One might be using the SAMs to increase the costs of adversary air operations, a force-in-being approach that seeks to add an operational drag on potential aggressors without exposing the SAMs to too much attrition. Another approach would be to think of the SAM force as one that supports other military operations to enable their success by reducing the air threat to which the operation is exposed for a finite period of time. Both of these concepts share a key operational principle: The SAMs choose when and where to operate, rather than letting the adversary dictate. Adopting this mind-set allows the SAMs to operate more survivably and thus for longer periods of time. This allows Taiwan to balance the SAMs' effectiveness and survivability demands—a balance that will change based on the overall goals Taiwan sets for the SAMs in the conflict and the specific threats they face. This gets away from a mind-set that SAMs need to continuously operate or that they should strive to achieve and sustain “air superiority” or keep the sky over Taiwan continuously clear of threats.

In practice, this means that, in certain circumstances, Taiwan can use its SAM forces opportunistically, seeking highly favorable exchange ratios. In such cases, Taiwan will engage adversary aircraft when there is a high probability that it can shoot them down with little risk of loss. This would involve turning SAM radars on for only short periods of time, when they are likely to see threats in a favorable situation; engaging targets within range; and then tearing the SAMs down and moving them. Such an approach might be attractive if the attacker is not really committed to the attack or if the threat force is susceptible to modest losses, tipping the balance to the point at which the attacker might simply quit. This could occur in cases in which Taiwan faced a coercive threat, but it would clearly not be the case in a major conflict, such as an invasion. In this latter case, something else would be needed for a successful defense.

In situations in which Taiwan wants to use its SAM force to enable other operations, the choice of timing and location will be dictated by the demands of the supported mission. In these cases, the surface-based air defenses would be used as a means of seizing airspace

control for limited periods of time in order to support military operations, such as the defense of Taiwan by ground forces, that require a degree of freedom of action and that otherwise would be very risky or even infeasible in the presence of a heavy, persistent air threat.

For surface defenses to support an operation, they need to seize control of the air to establish a rapidly expanding defensive bubble that allows Taiwan to sanitize a portion of airspace, hold it open, then escape while controlling the losses to both the SAM force and the units the SAMs are supporting. Ideally, this would include a layered strategy employing both long- and shorter-range air defenses to leverage their unique capabilities. The longer-range SAMs engage more-distant targets, and the shorter-range SAMs sweep the airspace of closer threats. The SAMs would kill a substantial number of aircraft in the defensive bubble they create, but the bubble's main purpose would be to push enemy aircraft far enough away from the supported forces to make air attacks few and ineffectual.

Organization of the Report

In Chapter Two, we examine the costs of current force structure and suggest some future cost reductions that could liberate funding for new capabilities, which we describe, and might improve Taiwan's ability to address future threats. The chapter ends with several force structure options that we estimate to be roughly cost-neutral. In Chapter Three, we compare these force structure options using three vignettes. The vignettes span a range of conflict intensity and air power challenges, from an invasion scenario to counterblockade operations. The analysis compares the effectiveness of the different force structure options in each of these vignettes. Chapter Four discusses the implications of the analysis for the future direction of Taiwan's military. We also provide four appendixes: Appendix A explains our methods for estimating costs; Appendix B describes our approach to analyzing the vignettes; Appendix C lists other systems we considered; and Appendix D describes results of analyses we did on additional aircraft in an air-sovereignty vignette.

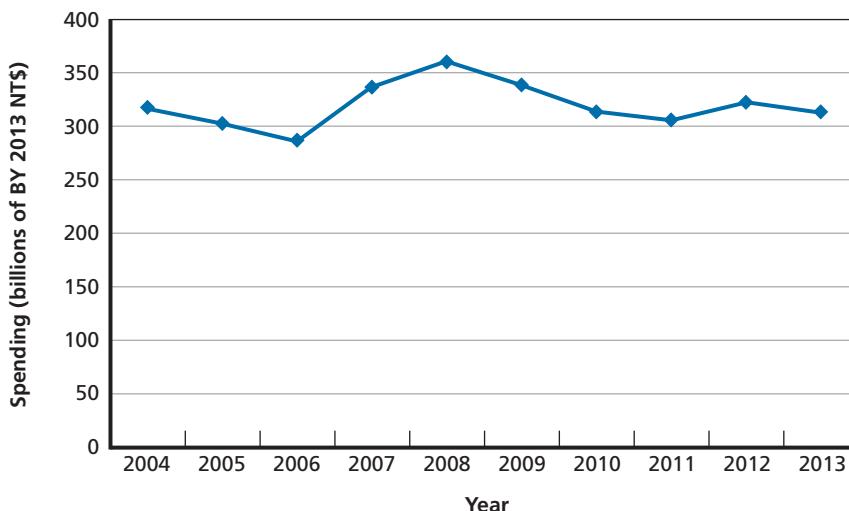
Force Structure

As highlighted in the previous chapter, Taiwan faces a daunting air-power challenge. Both its fixed-wing fighters and its ground-based air defenses face quality, as well as quantity, challenges. Given the fact that Taiwan spends about 2 percent of its gross domestic product (GDP) on defense annually, how can it best invest a portion of those funds to put its air defense force in position to impede PLA air operations and to achieve some meaningful operational goals? This chapter describes the ongoing cost of Taiwan's existing force and constructs several alternative future force structure options. Because we assume that there will be no major increase in the overall budget, nor in the share of the budget allocated to airpower capabilities, we have tried to create zero-sum options. That is, we calculate the costs of current systems and then make a series of divestments in order to free up resources for new investments. After estimating the costs of these potential new investments, we put them together in packages of roughly equal assessed cost.

Projected Cost of the Existing Force

From 2004 to 2013, Taiwan's annual defense budget averaged about NT\$320 billion (all cost estimates are in base year [BY] 2013 dollars), which is more than US\$10 billion (Figure 2.1). The amount fluctuated between NT\$300 billion in 2005, the year with the least funding in the decade, to NT\$360 billion in 2008. The defense acquisition budget has fairly consistently been just under one-quarter of the entire defense

Figure 2.1
Taiwan Defense Spending, 2004–2013



SOURCES: Ministry of National Defense of the Republic of China, 2013b; our analysis.

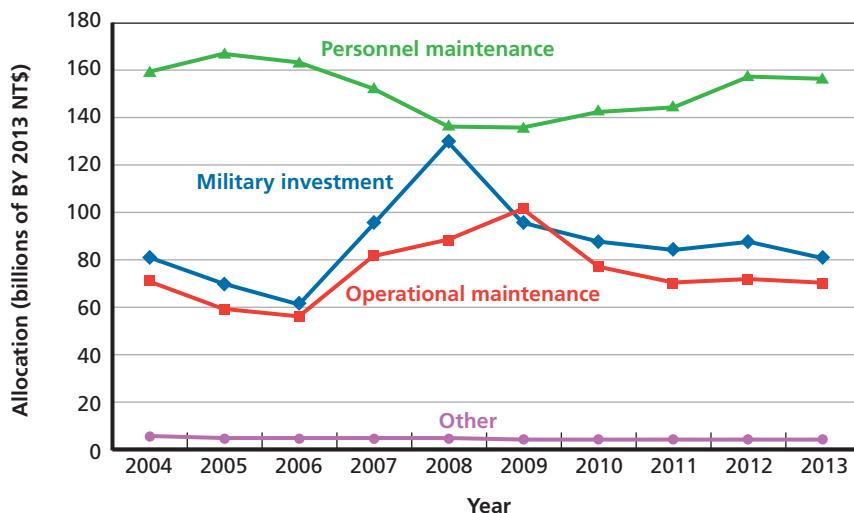
RAND RR1051-2.1

budget, averaging NT\$88 billion (US\$2.8 billion), but there have also been fluctuations in the amount, from NT\$60 billion to NT\$130 billion (Figure 2.2).¹ The high figure is from 2008 and is an outlier but is plausible in that, for several years before 2008, there had been a major political impasse in Taiwan over defense spending between the president and the legislature.

Taiwan operates a variety of airpower systems, including fighter aircraft and ground-based SAMs, which all consume budget resources annually. Table 2.1 summarizes the annual costs for three major airpower units. The table shows annual operating costs and estimates of the 20-year cost to keep that system in the inventory. Each fighter costs about US\$2.25 million per year, and, in the next 20 years, the entire fleet of fighters will cost about US\$25.3 billion. Given Taiwan's flat defense spending, these substantial outlays for legacy fighters deserve

¹ Budget figures are from the Ministry of National Defense of the Republic of China, 2013b, and adjusted by us to BY 2013 values.

Figure 2.2
Taiwan Defense Allocation, 2004–2013



SOURCES: Ministry of National Defense of the Republic of China, 2013b; our analysis.

RAND RR1051-2.2

scrutiny and should be compared with other possible directions for Taiwan's air defense investments.

Future Force Structure Options

To give insights about the strengths and limitations of future directions for Taiwan's air defense capabilities, we developed several cost-constrained future force structure options. These options show different mixes of fighters and SAM forces. In order to keep these options roughly within current budget levels, each (except for the baseline option) includes some divestment of current systems in order to pay for new systems. This allows us to explore whether the annual costs of existing systems could more productively be applied to other air defense capabilities. To get the most out of his or her sunk investment, a value investor might prefer to keep a system in the inventory until it wears out, and one of the options we consider represents the

Table 2.1
Annual Operating Costs of Three Major Airpower Units

Aircraft	Wing Annual Cost (millions of BY 2013 US\$)	Wing Total Aircraft	Wing's per-Tail Annual Cost (millions of BY 2013 US\$)	Total Tails in Inventory	Total 20-Year Fleet Costs (millions of BY 2013 US\$) ^a
F-16A/B	164.5	78	2.11	144	8,160
F-CK	132.6	57	2.33	127	7,938
Mirage	137.2	57	2.41	57	3,685

SOURCES: Unpublished data from Ministry of National Defense and our analysis.

NOTE: Operating costs consist of personnel costs, fuel consumption, equipment maintenance, unit maintenance, and exercise fuel and ammunition. To estimate a 20-year life-cycle cost for these units, we assume a 3-percent real discount rate for the time value of money over the next 20 years. Costs for military investment, facilities, and war reserve stocks were also reported but not used in calculations of operations and support (O&S) savings because these are treated as sunk costs.

^a Because aircraft flying hours vary and the costs to fly an aircraft are considerable, the annual cost of a fighter wing is driven by both the number of aircraft and the flying hours. Thus, if the flying hours for an aircraft were not representative of future operating practices, our cost estimates for that system might not reflect the actual budget that Taiwan would have to set aside to operate these aircraft in the future.

existing inventory, but the purpose of considering divestment in this analysis is to inform decisionmakers who might want to weigh opportunity costs of the current inventory. We tried to do this in an open, analytically based manner, recognizing that some of the options for both divestment and investment might not now be politically feasible. Nevertheless, recognizing that politics can change, we include some options so that policymakers can judge whether the political costs are worth incurring.²

In addition to divestments, Taiwan's military can be expected to devote a certain amount of its budget to new investments. From 2004 to 2013, Taiwan spent on average about NT\$87.5 billion on acquisition.³ Going forward, we assumed that, in real terms, the average

² The modernization ideas presented here are ours alone and do not necessarily represent the views of the U.S. government.

³ Ministry of National Defense of the Republic of China, 2013b; our analysis.

acquisition budget would be consistent with recent averages. Thus, we estimate that Taiwan could spend about NT\$2.35 trillion over the next 20 years on acquisition.⁴ Of that, we assume that 45 percent will be devoted to major acquisitions, and, of this, we assumed that about one-fifth, or NT\$211.7 billion (about US\$6.7 billion), would represent new investment in air defense.⁵

Upgrades to the current inventory could come from like systems or from investments in different capabilities. Focusing first on like systems, we have explored a range of fighter upgrades, from equipping current platforms with new systems, an upgrade in radars and weapons that Taiwan has long sought, to investing in entirely new systems, in this case, Joint Strike Fighter (JSF) short takeoff and vertical landing (STOVL) aircraft.

The various options introduce a variety of different surface-based air defenses into the possible mix. These consist of maintaining or adding to the existing TK III and Patriot air and missile defense systems or adding new air defense platoons.

Patriot is an advanced U.S. medium-range air defense system used by Taiwan. The PAC-3 variant has been optimized more for anti-tactical ballistic missile (ATBM) coverage and will be replaced in the U.S. inventory with the Missile Segment Enhancement (MSE) that enhances the missile segment to provide a much more capable interceptor that is better suited to a mix of air-breathing and ballistic missile targets.

The air defense platoon is patterned after the U.S. IFPC-2 platoon currently under development. It consists of a set of four multimissile launcher trucks, each with 15 launch tubes, command elements, improved Sentinel radar, and a command and control backbone

⁴ Again, applying a discount factor to future spending.

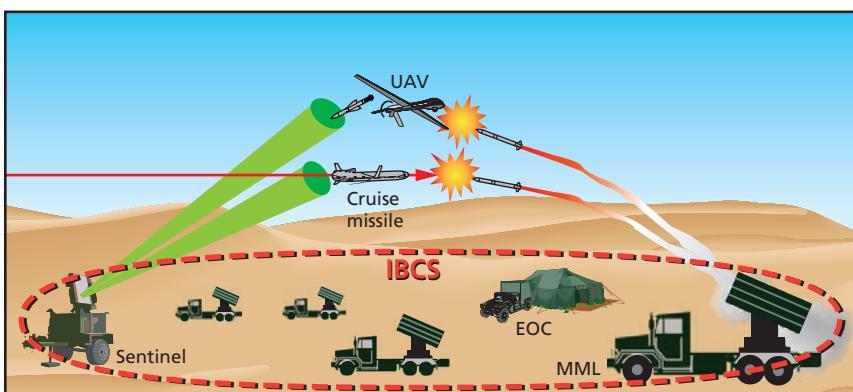
⁵ The U.S. experience indicates that about 44 percent of the procurement budget goes to major weapon systems. Examples of other weapon systems include “small arms and ammunition, communications equipment, cars and some other vehicles, protective gear for individuals, and engineering equipment” (Christopher Jehn, assistant director for national security, Congressional Budget Office, “Procurement Costs to Maintain Today’s Military Forces,” statement before the Subcommittee on Military Procurement, Committee on Armed Services, U.S. House of Representatives, September 21, 2000, p. 4).

called the Integrated Air and Missile Defense Battle Command System (IBCS) that is shared with the Patriot systems and provides the network connections for a common operating picture and cooperative engagement capabilities (see Figure 2.3). The initial configuration will use AIM-9X missiles, but future variants could add AIM-120 (Advanced Medium-Range AAM [AMRAAM]) active radar-guided missiles, which is included for consideration here. These have a longer range and are more capable than the AIM-9Xs. The program is currently under development by the U.S. Army and will not be available for export before 2018.

AIM-9X is the latest version of the Sidewinder IR-guided AAM. It is a shorter-range system with off-boresight capability that allows it to be fired and lock on after launch with no or minimal updates as to target location. In this application, the missile would be surface-launched against threats close to the launcher.

AIM-120 is an advanced medium-range air-to-air missile that possesses an active radar seeker, allowing the missile to self-guide after it locks onto the target. This missile has already been employed as part of the Norwegian advanced SAM system. This missile possesses significantly longer range than the AIM-9X and can engage targets at higher altitude.

Figure 2.3
Air Defense Platoon Concept



The improved Sentinel radar is a lightweight three-dimensional radar designed with a range of 75 km or more.⁶ When on its own trailer, it can be set up in 15 minutes or torn down in less than 10 minutes with a two-person crew. It can also be mounted on a variety of vehicles to improve mobility. The improved Sentinel is the key sensor in the IFPC-2 air defense system.

Table 2.2 summarizes estimated costs for these air defense systems: five types of fighter aircraft and two SAMs. These costs include the cost to procure additional systems not currently in the inventory, annual O&S costs for each system, and 20-year life-cycle cost estimates for each unit. It shows cost estimates for two components of the Patriot system, its interceptor missiles and the rest of the system. The air defense platoon costs would consist of sentinel radar, IBCS, IFPC-II, MML, and some number of AIM-120 and AIM-9X interceptor missiles. Appendix A has more information on our cost assessments.

Potential future force structures analyzed in this report are summarized in Table 2.3. They include different mixes of aircraft divestments and new investments in both fighter aircraft and SAMs. Further options are considered in Appendix D. The options include different levels of fighter aircraft divestment leading to four different force mixes between fighter aircraft and ground-based SAMs among the options considered.⁷ The complete force structure options all cost below cur-

⁶ An elevated Sentinel was reported by the manufacturer to have a range of 150 km or more against fighter-sized targets. See ThalesRaytheonSystems, “AN/MPQ-64F1 Improved Sentinel,” undated brochure; accessed July 3, 2014.

⁷ Past writings on future force structure options for Taiwan include Michael J. Lostumbo, “A New Taiwan Strategy to Adapt to PLA Precision Strike Capabilities,” in Roger Cliff, Phillip C. Saunders, and Scott Warren Harold, eds., *New Opportunities and Challenges for Taiwan’s Security*, Santa Monica, Calif.: RAND Corporation, CF-279-OSD, 2011, pp. 127–136; Michael D. Swaine and Roy D. Kamphausen, “Military Modernization in Taiwan,” in Ashley J. Tellis and Michael Wills, eds., *Strategic Asia 2005–06: Military Modernization in an Era of Uncertainty*, Seattle, Wash.: National Bureau of Asian Research, 2005, pp. 387–424; William S. Murray, “Revisiting Taiwan’s Defense Strategy,” *Naval War College Review*, Vol. 61, No. 3, Summer 2008, pp. 13–38; and Eric A. McVadon, “Joint Air and Missile Defense for Taiwan: Implications for Deterrence and Defense,” in Martin Edmonds and Michael M. Tsai, eds., *Taiwan’s Security and Air Power: Taiwan’s Defense Against the Air Threat from Mainland China*, London: RoutledgeCurzon, 2004, pp. 116–139.

Table 2.2
Cost Estimates for Major Air Defense Systems Considered, in Billions of
Base Year 2013 U.S. Dollars

Item	Acquisition Cost (PAUC)	O&S Costs (Annual)	20-Year Life-Cycle Estimate (per unit)
JSF STOVL (F-35B) fighter	156.85	13.3357	515.18
PAC-3 fire unit (launchers and radar)	274.02	5.187	413.41
F-16A/B retrofit fighter	23.74	2.11	80.44
Mirage 2000-5 fighter	N/A	2.41	64.76
F-CK/IDF	N/A	2.33	62.61
Sentinel radar AN/MPQ-64F1	8.65	0.992	35.32
IBCS	15.26	0.413	26.35
IFPC-2 MML	7.09	0.142	10.89
PAC-3 missile	4.11	0.071	6.01
AIM-120 missile	1.82	0.0144	2.21
AIM-9X missile	0.73	0.0145	1.12

SOURCES: Selected Acquisition Reports (SARs); Army Contracting Command; National Research Council Committee on an Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives, *Making Sense of Ballistic Missile Defense: An Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives*, Washington, D.C.: National Academies Press, 2012; Defense Security Cooperation Agency (DSCA) news releases of congressional notifications; and Taiwan Ministry of National Defense, unpublished O&S data. SARs are status reports provided to Congress for all Major Defense Acquisition Programs.

NOTE: PAUC = program acquisition unit cost. N/A = not applicable. IDF = Indigenous Defense Fighter. MML = multimissile launcher.

rent spending projections over the next 20 years, so Taiwan can afford these options by maintaining current levels of funding.

The Baseline force option represents Taiwan's current capabilities plus gives credit for the full retrofit program, although it has not

Table 2.3
Force Structure Options

Option	Baseline	Mixed Force	JSF-Only Force	SAM-Dominant Force
F-16s retrofit	144	144	0	50
F-CK/IDF	127	0	0	0
Mirage 2000-5	57	0	0	0
JSF STOVL (F-35B)	0	0	57	0
Additional AIM-120	576	2,676	228	1,800
Additional PAC-3	0	4 batteries, 300 interceptors	0	13 batteries, 975 interceptors
Air defense platoons	0	21	0	40
Modernization investment estimate (billions of BY 2013 US\$)	6.7	6.7	6.7	6.7
Total cost (billions of BY 2013 US\$)	-2.008	-0.882	-0.033	-0.480

SOURCES: Data for the cost assessment come from SARs, contractor cost data reporting, and Cost Performance Reports. The companies performing the work generate contractor cost data reporting reports. DSCA publishes a news release for each contracted sale to a foreign entity, which was another source for cost information.

NOTE: The air defense platoon is a concept that we developed drawing from new capabilities being developed by the U.S. Army. It consists of four IFPC-2s, two Sentinel radars, 80 AIM-9Xs, and IBCS network capability that allows cooperative engagement. It also includes 40 AIM-120 missiles, which are compatible with the system and could be a future enhancement to the Army program. Cost figures reflect 20-year life-cycle estimates. Negative numbers represent savings.

been fully funded and will take years to implement.⁸ The Mixed Force option retires all the Mirage and the F-CK fighters while retrofitting

⁸ Taiwan has currently paid \$2 billion and has a \$1.7 billion balance remaining for part of the retrofit package announced in September 2011. Several remaining items will need to be purchased in the future, including the Electronic Countermeasures pods, SNIPER targeting systems, Joint Helmet Mounted Cueing System, and AIM-9X missiles.

the existing F-16s. The Mixed Force option also invests in SAMs: adding four new PAC-3 batteries and 21 air defense platoons. It also invests in capabilities to network the SAM forces to produce a common operating and engagement capability. The JSF-Only Force retires all current fighters to purchase 57 JSF STOVLs (F-35Bs) but makes no SAM investments. The SAM-Dominant Force retires all fighter aircraft, except for 50 F-16 retrofit, in favor of investing in SAMs. This option fields 13 new PAC-3 batteries, 40 air defense platoons, and the ability to network all these systems.

The SAM investments are intended to increase Taiwan's ability to protect its airspace. These options allow us to examine different mixes of a variety of ground systems. Some are capable of intercepting ballistic missiles, but we are considering this investment for purposes of intercepting fixed-wing aircraft and cruise missiles, not ballistic missiles.

Vignettes and Analytic Results

To compare the performance of the options, we have developed three vignettes spanning a diverse range of possible conflicts and stressing different aspects of airpower. In the Air Sovereignty vignette, China imposes a blockade on Taiwan. In the Disarming Strikes vignette, China seeks to set the conditions for an invasion without actually launching one. This involves an attempt to substantially draw down Taiwan's fighter and SAM force. Finally, the Invasion Air Defense vignette involves applying air defenses to solve some operational problems posed by an invasion.

Other vignettes might potentially inform resource allocation decisions for Taiwan, but these were selected because they allow us to examine a range of conflicts, from very constrained to fairly unconstrained; they test how both the fighter and SAM forces contribute to air defense; and they are plausible. As one of its military strategic missions, Taiwan has identified a counterblockade scenario to maintain sea and air lines of communication,¹ which is the subject of the Air Sovereignty vignette. This vignette features high levels of restraint on the part of both China and Taiwan.

Ultimately, China could find ways to destroy, or send underground, Taiwan's air defense capabilities, but that would entail a fairly violent attack. Considering a very restrained use of force in force planning might be justified for two reasons. Historically, there have been situations, such as Operation Desert Fox, in which a stronger power has

¹ Ministry of National Defense of the Republic of China, *2013 Quadrennial Defense Review*, March 13, 2013a, pp. 39–40.

used military force but exercised restraint in trying to coerce a weaker power. As of summer 2014, competing and overlapping air defense identification zones have been declared along the western Pacific rim that already lead to situations just short of those in this vignette, which suggests that it might be of interest to air defense planners to consider something along the lines of the Air Sovereignty vignette. The other two vignettes perhaps need less justification. Operations conducted in those vignettes could support two other identified military strategic missions of Taiwan's defense forces: joint interdiction and ground defense.² The vignettes are meant to test how long Taiwan could operate, not hide, air defenses under violent attack, which can provide a good yardstick for measuring the combat value of future air defense investments.

Vignette 1: Air Sovereignty

In this vignette, the PRC seeks to influence Taiwan by establishing a maritime blockade of the island. In carrying out this blockade, the intention is to use the threat of force to deter commercial ships from traveling to Taiwan in hopes that a steep reduction in maritime commerce will put pressure on Taiwan's authorities to accede to PRC demands.

To implement the blockade, the PRC declares an exclusion zone around Taiwan and threatens to confiscate any goods traveling on ships that violate PRC law. The PLA uses surface vessels to implement the blockade. From those vessels, the PLA can launch boarding parties on either helicopters or small boats against any vessel deemed in contravention of the law. The PLA air support to these operations provides air cover to maritime surface operations and airborne ISR to maintain maritime situational awareness.

For its part, Taiwan chooses not to capitulate; however, its leaders recognize that the situation could worsen. As a result, Taiwan seeks to

² Ministry of National Defense of the Republic of China, 2013a, pp. 39–40.

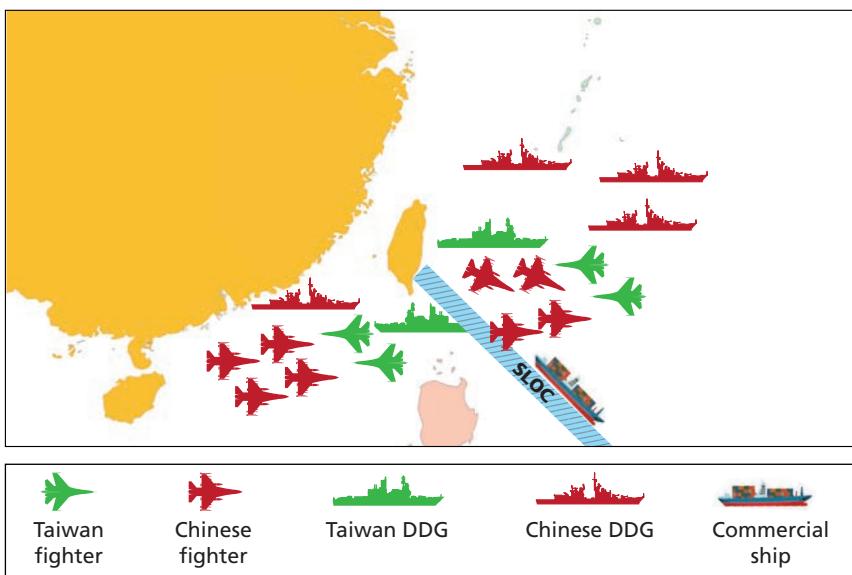
get supplies of vital necessity through the blockade but to instruct its military to operate using maximum restraint.

The Republic of China (ROC) Navy is called on to keep sea lines of communication (SLOCs) open so that Taiwan can receive vital supplies. The ROC concept involves keeping a route to the island clear of military threats and escorting convoys of ships through these routes. Mine-sweeping ships operate in the ports and coastal areas around the ports Taiwan seeks to keep open. Maritime patrol aircraft monitor for PLA submarines, and the surface fleet conducts operations to both escort convoys and interdict threats as they arise. These could include surface, subsurface, and air threats. This counterblockade concept is illustrated in Figure 3.1.

The air defense component of the ROC concept involves a desire to not strike the first blow and to keep any conflict to a minimum and not have it escalate. Within that context, the Taiwan air defense concept seeks to maintain secure airspace over Taiwan and to protect the maritime approaches from air threats. In carrying out these tasks, Taiwan operates both air-sovereignty CAPs over Taiwan and airspace protection from ground-based SAMs. In addition, aircraft remain continuously on alert to sortie out beyond Taiwan to protect the surface fleet when threatened by adversary aircraft. A further supporting mission is to disrupt adversary ISR aircraft.

The interaction of the opposing goals creates combat potential when PLA aircraft try to support the PLA's maritime assets enforcing the blockade and Taiwan's aircraft counter to try to support Taiwan's maritime assets in disrupting the blockade. In the vignette, we analyze encounters between two fighter aircraft from Taiwan against four PLA aircraft. Initially, in these encounters, Taiwan tries to warn away opposing warplanes from threatening friendly ships, but eventually the PLA does attack aircraft from Taiwan, and Taiwan retaliates in kind. The retaliation is limited in time and space to the aircraft that take hostile action against assets from Taiwan, which limits the lethality of the engagements; nonetheless, these encounters do recur over time.

Figure 3.1
Counterblockade Concept



Air Sovereignty Vignette Analytic Results

To study Taiwan's force structure requirements, we developed and analyzed a range of possible outcomes, with varying degrees of air-to-air engagements, between Taiwan's fighters on CAP and PLA fighters that challenged these CAPs over time.

Taiwan had sought to keep a technology edge over China but has now lost that advantage. Currently, the two sides are close to parity in terms of the abilities of their air-to-air systems. The capability of Taiwan's fourth-generation fighters (F-16, F-CK, and Mirage 2000), armed with AIM-120, MICA, and TC-2 medium-range AAMs, is comparable to that of current PLA fighters (J-10, J-11A FLANKER, and J-11B Mod FLANKER) and their complement of active and semi-active medium-range missiles (PL-12, AA-12, and AA-10), but, when future PLA systems, such as the J-16, come on line armed with advanced air-to-air weapons, they will eclipse Taiwan's current fighters.

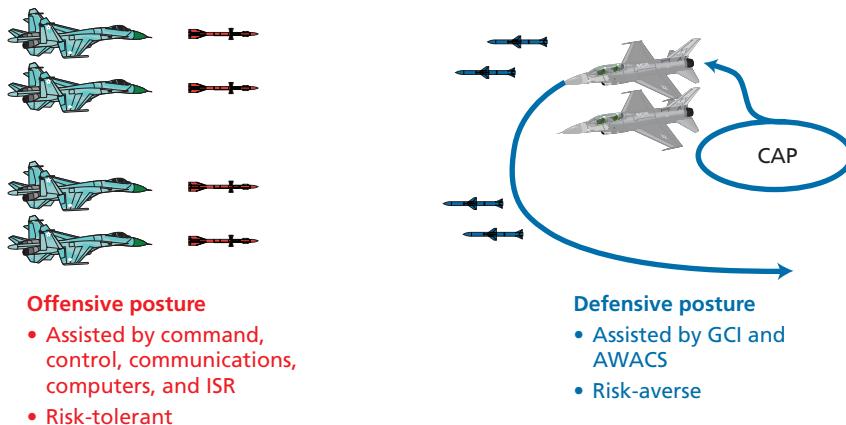
The introduction of the fifth-generation JSF STOVLs would add significant combat capabilities, such as stealth, AESA radar, advanced fire control, and defensive avionics, that would vastly exceed the combat capabilities of not only current but also developmental PLA fighters and missiles (Advanced J-10B, J-11B upgrade, PL-12 upgrade, and PL-10). All of these fighters are capable of detecting, tracking, and engaging adversary aircraft at BVR, especially when cued by supporting ground control or airborne warning and control system (AWACS) aircraft, such as the PLA KJ-2000 MAINRING and Taiwan's H-2T HAWKEYE.

In this vignette, we postulate that Taiwan would establish seven CAPs, which is the minimum number of CAPs to provide Taiwan with complete geographic coverage of the island from threats in all directions. If Taiwan chose to fill each CAP with two fighters, then a minimum of 43 fighters would be required for 12 hours of coverage for daytime-only operations; 24-hour operations would require twice as many, or 86 fighters. Once available inventory dropped below this value, Taiwan would be unable to support all CAPs. Furthermore, a certain percentage of the fighter inventory will be undergoing maintenance or otherwise not available for combat. In this analysis, we assumed that 20 percent of the total inventory would be down for maintenance.³ To account for variability and uncertainties in this simple attrition methodology, we also applied an arbitrary error bound of plus or minus two losses around the predicted average loss rate.

The basis of our analysis stems from what we consider to be a *representative* and *scalable* 2v4 engagement, posture, and associated tactics, as depicted in Figure 3.2. The figure illustrates how two defender aircraft flying a CAP mission move to intercept four attackers as they approach their position. The defenders are risk-averse and attempt to engage the attackers quickly before turning to survive the encounter. The attackers are willing to take more risk, though; in the context of this coercive vignette, they are charged with protecting Red (adver-

³ We assume that this figure is quite generous. There have been reports of readiness problems with the fighter aircraft. Some of the savings from force structure options considered in this report might need to be invested in future readiness.

Figure 3.2
Representative Air Combat Scenario: 2v4



RAND RR1051-3.2

sary) surface combatants operating to enforce a blockade. Although other air-to-air engagements could be considered, we believe that this vignette is representative of the type of air-sovereignty mission that Taiwan might find meaningful in future force structure decisions about its air defense capabilities.

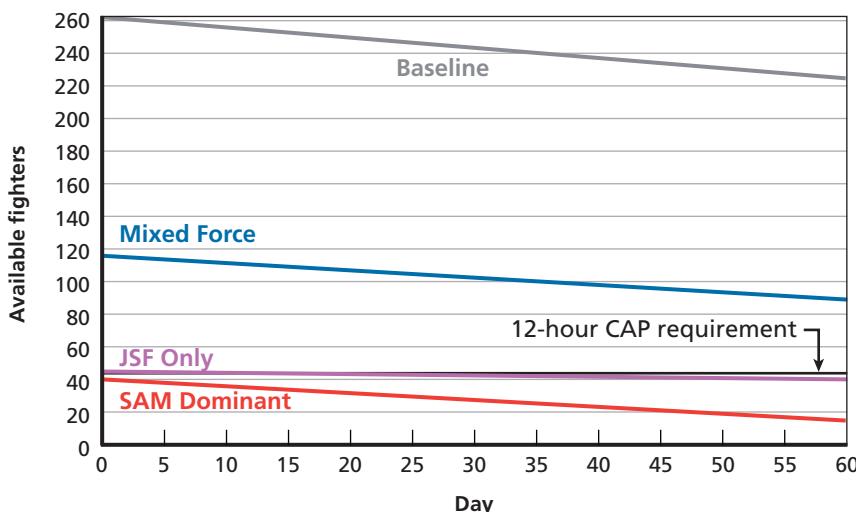
The outcome of the engagements is influenced by a variety of factors attributed to each aircraft and weapon type that allow us to estimate the probability of kill (Pk) in an engagement; these estimates are specified in Appendix B. This captures differences in the capabilities of each fighter, with weaker systems less likely to register kills and more likely to suffer attrition and better systems more likely to survive and, in some cases, able to fire more weapons. In our estimation, against current threats, the F-CK/IDF has the poorest exchange ratio and the F-16A/Bs and Mirage have somewhat better exchange ratios, but all three of the current systems have exchange ratios of less than one, meaning they would suffer more losses than they would score kills. In contrast, we assess the retrofit F-16 and JSF STOVL as enjoying a favorable exchange ratio against current threats, but only the JSF will keep that advantage over developing threats.

The key input influencing the rate of losses in our analysis is the presumed frequency of air combat: The more frequently the PLA challenges the fighters, the more quickly Taiwan's forces are drawn down. To provide insight into the relative drawdown of each force structure option, we present three levels of conflict: low, medium, and high.

Current Fourth-Generation Fighter Threats

The results of our analysis indicate that all four force structure options can hold out against PLA incursions in a *low-intensity* conflict, in which the frequency of combat is only one CAP engagement per day (see Figure 3.3). However, the smallest option is unable to support the 12-hour CAP requirement because the sizes of the force are below the minimum requirement. Once that occurs, Taiwan would, in theory, have to choose between either ceding portions of its airspace or changing the way that it responds to PLA aircraft incursions, such as putting

Figure 3.3
Fighter Attrition over Time: Low-Intensity Conflict



NOTE: *Low intensity* here means one CAP engaged per day. Baseline has 328 F-16 retrofit, F-CK/IDF, and Mirage aircraft. Mixed Force has 144 F-16 retrofitted aircraft. JSF Only has 57 F-35B aircraft. SAM Dominant has 50 retrofitted F-16 aircraft. All vignettes assume that 80 percent of the force is available for combat.

remaining fighters on strip alert and waiting for orders from ground or airborne controllers (GCI or AWACS).

Figure 3.4 shows results for a *medium-intensity* conflict in which three CAPs are engaged every day. In this scenario, three of the options—Baseline, Mixed Force, and JSF Only—can hold out for a considerable period. The SAM-Dominant Force option is essentially depleted after 30 days of conflict. The JSF STOVL's excellent survivability suffers very few losses over a 60-day period. Interestingly, although far less capable and survivable, because of its superiority in numbers, the largest fighter force option (Baseline) can also defend Taiwanese airspace for a long time.

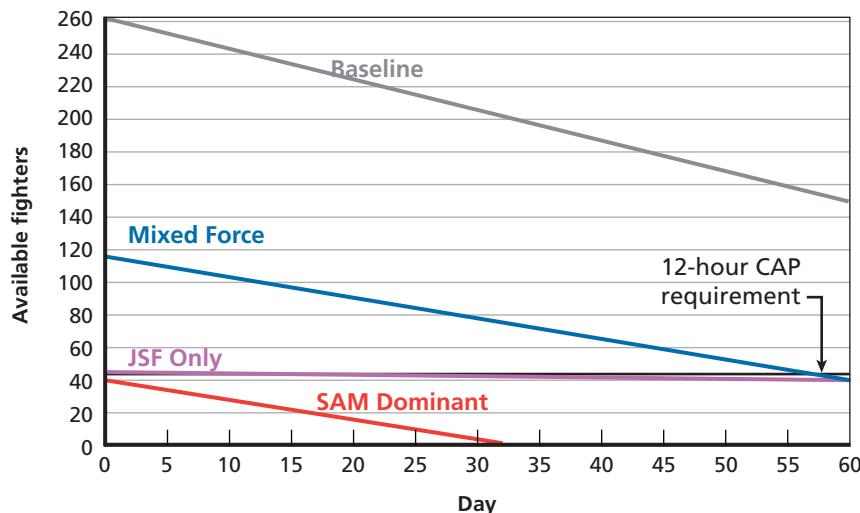
Of course, higher levels of conflict are possible between China and Taiwan.⁴ In Figure 3.5, Taiwan experiences higher loss rates when all seven CAPs are repeatedly engaged every day. This frequency of combat is considered to be well within the maximum sortie rates that fighters on Taiwan and China are both capable of performing.

Although certainly with Figure 3.5 we have pushed the boundaries of a coercive vignette, and the rate and number of engagements worth considering are numerous, Figure 3.5 illustrates well the relative ability of the different options to sustain combat over time. It shows that, against current PLA aircraft, several of the options are drawn down fairly quickly, while the most capable aircraft suffer losses at a much slower rate.

In a *high-intensity* conflict, the Baseline force can hold out against PLA incursions for 62 days, whereas the smaller Mixed Force is effectively depleted after 36 days. Note also that these cases all assume that 80 percent of the force is available, but Taiwan would probably have to increase spending for readiness to achieve such rates in the future. In theory, the JSF-Only Force holds out the longest, although one has to question the efficacy of such a small force after 60 days of repeated conflict.

⁴ High-conflict vignettes in which the Taiwan's fighters played a significant air defense role would likely have a higher frequency of engagements and likely feature more fighters. These factors might change the force ratios. However, as described elsewhere in this report, if it is willing to attack Taiwan's air bases with missiles, the PLA can strongly influence the number of Taiwan's fighter aircraft able to fly.

Figure 3.4
Fighter Attrition over Time: Medium-Intensity Conflict



NOTE: *Medium intensity* here means three CAPs engaged per day. Baseline has 328 F-16 retrofit, F-CK/IDF, and Mirage aircraft. Mixed Force has 144 retrofitted F-16 aircraft. JSF Only has 57 F-35B aircraft. SAM Dominant has 50 retrofitted F-16 aircraft. All vignettes assume that 80 percent of the force is available for combat.

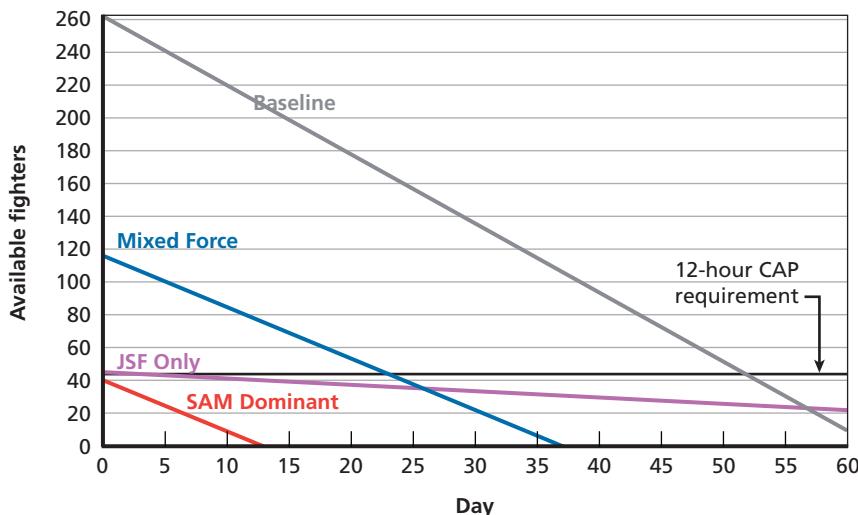
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An important caveat with all these options is the assumption that adequate stocks of AIM-120 AMRAAM missiles are available for the duration of the conflict, either through resupply or additional missile purchases.

For *high-intensity* conflicts, AIM-120 missile use rate is *28 missiles per day*, which would deplete missile inventories after a few days of conflict. Thus additional missiles would need to be procured in order for this option to be viable for the length of time depicted in Figure 3.5. In this vignette, we did not investigate this degree of balancing missile use to assessed aircraft attrition.

In a coercive scenario like this, the defender's ability to take and endure the pain of the conflict is a key metric, so we have shown the length of time for which each option could sustain operations. The ability to support a 12-hour CAP requirement is effectively gone in a matter of days to a few weeks in this high-intensity conflict scenario.

Figure 3.5
Fighter Attrition over Time: High-Intensity Conflict



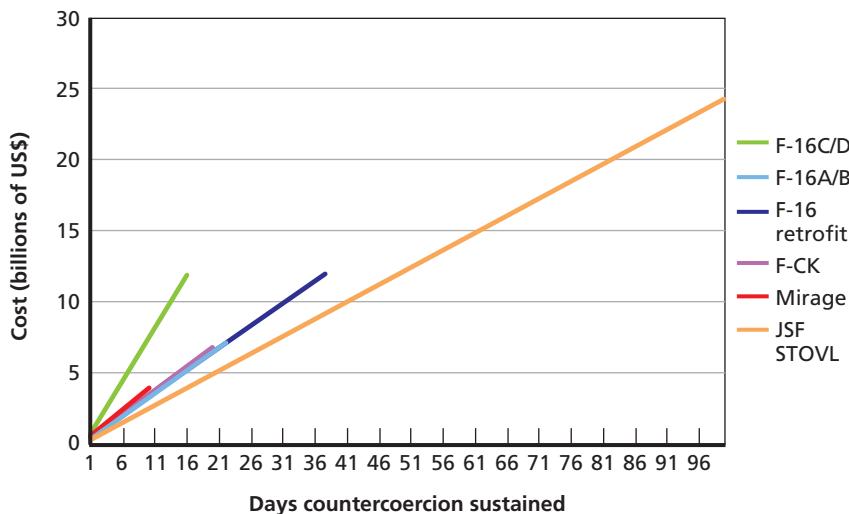
NOTE: High intensity here means seven CAPs engaged per day. Baseline has 328 F-16 retrofit, F-CK/IDF, and Mirage aircraft. Mixed Force has 144 retrofitted F-16 aircraft. JSF Only has 57 F-35B aircraft. SAM Dominant has 50 retrofitted F-16 aircraft. All vignettes assume that 80 percent of the force is available for combat.

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For Taiwan to hedge against this type of conflict, a more comprehensive and sustainable air defense force structure needs to be examined, especially when one considers the potential impact of advanced fighter weapon systems that the PLA will field in the 2020 time frame.

Another consideration might be how much it costs to sustain air-sovereignty operations. Figure 3.6 shows the cost per day of sustained operations in this vignette but looks at platform types rather than the force structure options. It shows that, although the JSF is the most costly option, it also outperforms other platforms by a considerable margin because of its survivability. The F-16A/B and retrofit, as well as the F-CK and Mirage, are all on similar cost profile slopes, but again the greater survivability of the F-16 retrofit allows it to sustain operations for longer. Although just as survivable as the F-16 retrofit, the F-16C/D performs the worst in this cost-effectiveness dimension because of the higher unitized cost of the small force.

Figure 3.6
Cost per Days Surviving Against the Current Threat

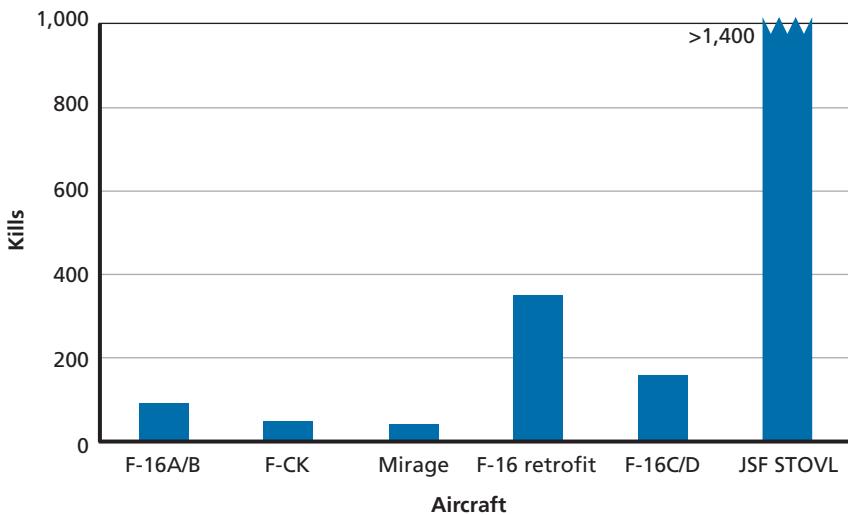


NOTE: Shows days surviving when seven CAPs are engaged per day with each of these engagements a 2v4. Force sizes are 66 F-16C/D, 144 F-16A/B, 144 F-16 retrofit, 127 F-CK, 57 Mirage, and 57 JSF STOVL aircraft. All types are assumed to have 80 percent of the aircraft available.

RAND RR1051-3.6

In a coercive scenario like this, it is not only the losses to Taiwan that factor into calculations of winners and losers. The losses the attacker sustains in carrying out the blockade could also influence whether the attack is sustainable. Figure 3.7 shows the number of attacker losses suffered over the duration of the period for which each platform is able to sustain operations, drawn from Figure 3.6. It shows that, against current threats, the JSF can exact attrition that is off the scale compared with the other platforms. It also shows that, because of improvements to electronic countermeasures and air-to-air missiles, the F-16 retrofit investment makes it a much more lethal platform. Compared to equal numbers of the F-16A/B, the F-16 retrofit kills almost four times the number of attackers. On a per-aircraft basis, the F-16C/D is equally effective as the retrofit variant; however, the figure shows how force size influences effectiveness by comparing 66 F-16C/Ds and 144 F-16 retrofits.

Figure 3.7
Red Losses, by Platform, Current Threat



NOTE: Shows Red losses when seven CAPs are engaged per day with each of these engagements a 2v4. Force sizes are 144 F-16A/Bs, 144 F-16 retrofits, 127 F-CKs, 57 Mirages, 66 F-16C/Ds, and 57 JSF STOVLs. All types are assumed to have 80 percent of the aircraft available.

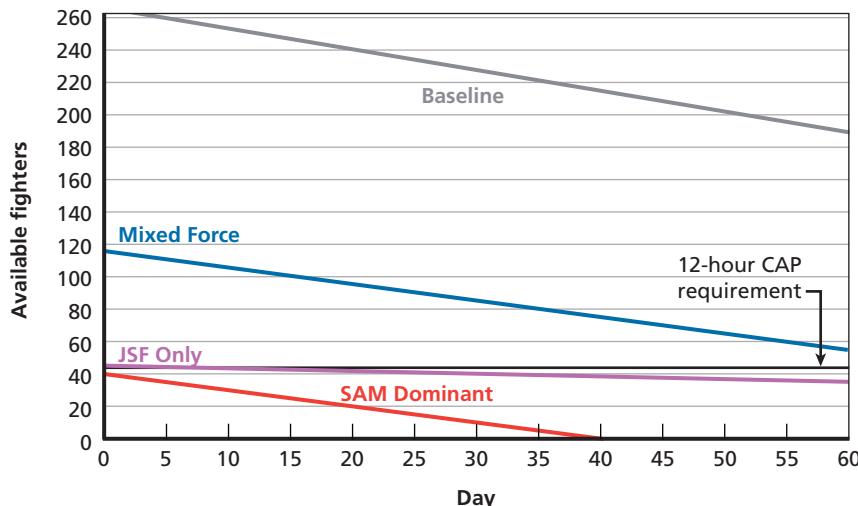
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Development Fighter Threat Excursion

China's continued development of fighter weapon systems will almost certainly have significant impacts on Taiwan's air force structure options. We examined the impact of one specific developmental system: the J-11B upgrade (J-16), armed with improved PL-15 AAMs. The results of this sensitivity analysis are shown in Figures 3.8 through 3.10. The combined evolutionary improvements in Chinese radar, EW, and AAM performance could seriously degrade the survivability of legacy fourth-generation fighters either in service today or part of a future force option being considered for Taiwan. It is plausible that only fifth-generation fighters, such as the F-22 and JSF, will be able to counter a numerically superior fourth-generation "plus" fighter, such as J-16, if operated by a determined and competent pilot.

In summary, our analysis of the impact of China's near-term development of an advanced J-11B FLANKER (J-16) armed with

Figure 3.8
Fighter Attrition over Time Versus PL-15 Threat: Low-Intensity Conflict Against Developmental Threats



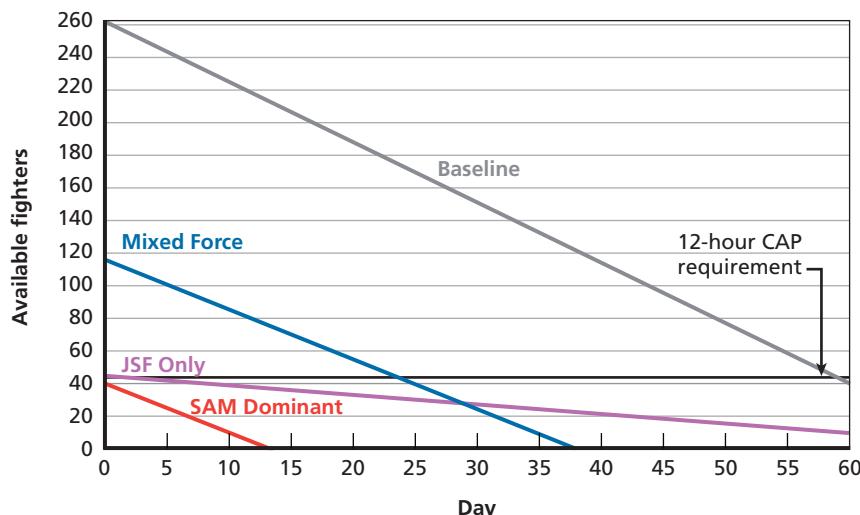
NOTE: The figure assumes that one CAP is engaged per day. Baseline has 328 F-16 retrofit, F-CK/IDF, and Mirage aircraft. Mixed Force has 144 retrofitted F-16 aircraft. JSF Only has 57 F-35B aircraft. SAM Dominant has 50 retrofitted F-16 aircraft. All vignettes assume that 80 percent of the force is available for combat.

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PL-15 AAMs essentially reduces the survivability of each force option by more than a factor of two. For example, in high-intensity conflicts, the legacy forces suffer steep attrition and are drawn down quickly, lasting between five and 31 days against the J-16/PL-15. The most promising, JSF-Only Force, holds out slightly longer than the largest option but, it is important to note, sustains losses at a much lower rate.

The SAM-Dominant Force is depleted in a few days, whereas the Mixed Force is assessed to last a couple of weeks. The underlying factor behind these high loss rates is the assumed improved performance of the PL-15 compared with that of current AIM-120 missiles (see Appendix B).

Figure 3.9
Fighter Attrition over Time Versus PL-15 Threat: Medium-Intensity Conflict Against Developmental Threats



NOTE: The figure assumes that three CAPs are engaged per day. Baseline has 328 F-16 retrofit, F-CK/IDF, and Mirage aircraft. Mixed Force has 144 retrofitted F-16 aircraft. JSF Only has 57 F-35B aircraft. SAM Dominant has 50 retrofitted F-16 aircraft. All vignettes assume that 80 percent of the force is available for combat.

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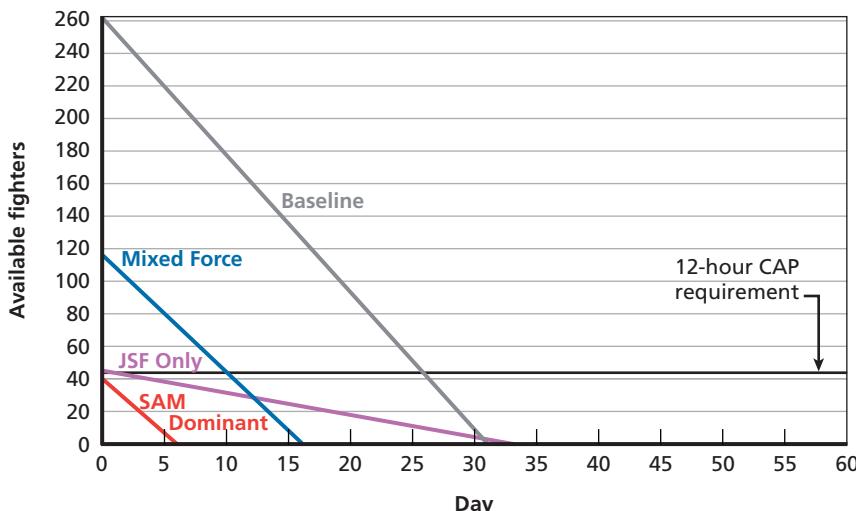
The J-20 Impact and the Future of Air Combat with Taiwan

The impact of other advanced PLA fighters in development, such as the J-20 and J-31, could, in theory, exacerbate these fighter losses even more; however, the true impact of J-20/J-31 cannot be adequately quantified given the immaturity of the design and uncertainty regarding PLA expected employment. Furthermore, we are unsure whether the PLA would even choose to use these limited fighters against Taiwan in the 2020–2025 time frame and instead reserve their use against more-capable adversaries in theater (e.g., the F-22).

Air Sovereignty Vignette Insights

Our analysis shows that force size and capabilities are the primary factors in distinguishing the performance of the options. Three of the options differ primarily in their size. Only the JSF option changes the

Figure 3.10
Fighter Attrition over Time Versus PL-15 Threat: High-Intensity Conflict Against Developmental Threats



NOTE: The figure assumes that seven CAPs are engaged per day. Baseline has 328 F-16 retrofit, F-CK/IDF, and Mirage aircraft. JSF Only has 57 F-35B aircraft. SAM Dominant has 50 retrofitted F-16 aircraft. Mixed Force has 144 retrofitted F-16 aircraft. All vignettes assume that 80 percent of the force is available for combat.

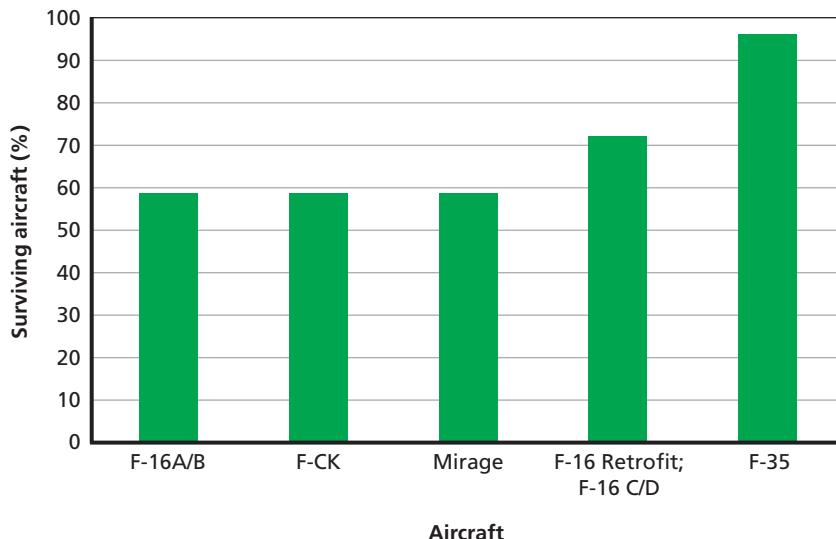
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slope of the drawdown curve because of its greater survivability, as depicted in Figures 3.11 and 3.12.

The largest but least survivable Baseline force was found to be capable of defending Taiwan airspace in a blockage scenario from one to two months, depending on the capabilities of the opposing PLA fighter. The SAM-Dominant Force is viable only for *low-intensity* conflicts against current near-peer threats. The Mixed Force was able to counter *high-intensity* incursions for 16 to 36 days, or approximately half as long as the Baseline force.

The small but highly capable JSF-Only Force was found to be competitive with the vastly larger Baseline force; unsurprisingly, the JSF-Only Force was the most capable against developmental PLA fighters armed with PL-15 missiles. However, the relatively small size of this force cannot support seven CAPs for 12 hours per day, which

Figure 3.11
**Fighter Aircraft Survivability Against Current People's Liberation Army
Fighters**



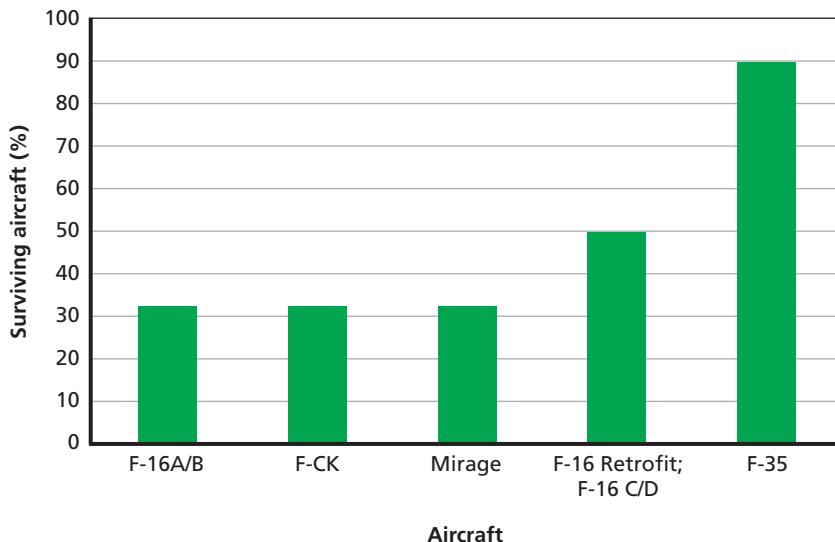
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would force limitations and changes in how Taiwan approaches air-space control. For Taiwan to consider this force, as well as the even smaller SAM-Dominant Force, the concept of prepositioning fighters on defensive CAPs would have to be reconsidered and probably forsaken in lieu of strip alert. The attractiveness of smaller but effective air forces needs to be weighed against force management challenges that come with operating a small number of aircraft of a given platform.

Vignette 2: Disarming Strikes

The PRC attempts a more emphatic means of coercing Taiwan in this vignette by setting the conditions for invasion without actually attempting to land any forces in Taiwan. The PRC's concept involves striking military targets, including air defense assets, to incapacitate key Taiwanese defenses. By doing so, the PRC hopes to destroy enough

Figure 3.12
Fighter Aircraft Survivability Against Developmental People's Liberation Army Fighters



RAND RR1051-3.12

of Taiwan's military to sow doubt about its ability to offer any serious resistance. This could make its inhabitants feel vulnerable to imminent invasion and might also influence the perceptions of third parties about the viability of supporting such a depleted partner. The PRC believes that the threat of uncontested further escalation will force Taiwan to concede.

The PLA attack would proceed as described in Chapter One, starting with ballistic and cruise missiles overwhelming Taiwan's fixed and mobile air defenses followed by attacks on EW radars and air bases. A key difference is that this attack is not in preparation for an immediate amphibious invasion and is therefore more open-ended. Attacks in this vignette are designed to give the PLA air superiority over Taiwan by destroying Taiwan's long- and medium-range SAMs, its air force, and its EW radars. If successful, the PRC can then fly aircraft over Taiwan with impunity, attacking targets at will and contributing to its coercive goals. As described in Chapter One, we assume that these actions give

the PRC the capability to either destroy aircraft on the ground or force them into mountain hiding places that might keep the aircraft safe but does not allow them to generate any sorties while under these threats, so Taiwan's fighter aircraft do not play a role in this or the following vignette.

Taiwan seeks to implement a measured response that tries to protect some IADS assets and exact some retribution because Taiwan cannot be certain how or when these attacks will end. In fact, some in the Taiwanese government feel that these actions are just a prelude to future, more-intensive attacks, and the possibility of invasion is not discounted. We assume that Taiwan hides its Patriots/TK IIIs to conserve them to respond to possible escalatory actions that the PRC could take.⁵ Instead, Taiwan activates a fraction of its shorter-range SAM systems to prevent the PLA from flying over Taiwan and degrading its defenses using direct-attack weapons, which China has in essentially endless supply. If Taiwan can force Chinese aircraft to attack using standoff weapons from some distance by causing enough attrition to aircraft, China must expend expensive weapons that are in short supply—weapons that it would need if it were to mount an invasion.

We also assume that, in the JSF-Only Force option, Taiwan would choose to not fly the JSF STOVLs, preserving them to use against a possible invasion. Even if the PRC did not attack air bases, the JSF STOVL would be flying from a disadvantageous position. With the Patriots/TK IIIs held in reserve (and without an effective medium-range SAM in this option), the PRC could position fighter CAPs directly over Taiwan, forcing the JSF STOVL into air-to-air combat very quickly after takeoff, where the JSF STOVL would be disadvan-

⁵ Because it lacks the mobility to cleanly escape before a ballistic missile attack could be put together to attack its radar, we assume that a Patriot/TK III that hides initially and then engages from ambush for an extended period will suffer heavy attrition. In many cases, each Patriot/TK III would then trade itself for the aircraft it could kill with its ready missiles. Even if the Patriot/TK IIIs survived to shoot all their missiles at aircraft, even the SAM-Dominant Force structure, with nearly 2,500 missiles, does not have enough missiles to shoot down half of the PRC air force (assuming the best Pks derived in Appendix B). Although the loss of a significant fraction of its air force in exchange for Taiwan's Patriots/TK IIIs would hurt the PRC, it would still retain hundreds of aircraft and, from that point on, could operate those with little impediment.

taged by the close range and its low altitude. Also, with only 57 JSF STOVLs, the PRC would always have many more aircraft and UAVs in the air, and some aircraft would likely be able to follow the JSF STOVL to its landing strip and direct a strike. Another consideration is that, because Taiwan would likely also save its antiship weapons for a possible invasion, the PRC navy would have ships with sophisticated long-range SAMs positioned around Taiwan that would be an additional threat to the JSF STOVLs.

The options introduce a new, highly mobile medium-range SAM, the air defense platoons, in order to give Taiwan an air defense capability that can engage PRC aircraft and escape, potentially many times over a long coercive campaign. An air defense platoon consists of four MML vehicles, two Sentinel radars for target acquisition and fire control, and a command vehicle. These MML vehicles notionally have 15 launch tubes and carry a mix of AIM-120 and AIM-9X missiles.

The goal of the air defense assets allocated to active protection of Taiwan is to exact attrition of PRC aircraft while controlling for losses. Thus, Taiwan's SAMs engage enemy aircraft only when there is a high probability of kill and when the threat environment appears to allow time to move the SAM forces before a retaliatory strike can be effective.

An exemplar attack by fighters on the air defense platoons would occur when a small number of fighters came within range of the AIM-120 missiles on the MMLs. The Sentinel radar network could be cued in various ways: in response to bombs striking targets, from visual or auditory observers, or even at random intervals. The Sentinel's modern AESA radar would be able to form target tracks on multiple targets within a few seconds. The Sentinel radar acts as both the acquisition and fire control radar for the air defense platoon. Because the active seeker on the AIM-120 missile is reported to have a 10-km effective range,⁶ the Sentinel does not have to deliver a precise track. It also does not have to provide guidance to the missile all the way to the target but can stop emitting when the missile seeker is within range, thus improving survivability of the radar.

⁶ "AIM-120 AMRAAM (Advanced Medium Range Air-to-Air Missile)," *Jane's Air-Launched Weapons*, August 14, 2014.

If the air defense platoon engages four fighters at 20 km, the engagement would be complete in as little as 45 seconds after the Sentinel radar turns on.⁷ Further, the Sentinel radar can turn off after approximately 30 seconds, when the last AIM-120 missiles get to their active seeker range. In response, if the Sentinel radar moves after engagements, it could expect to be attacked only by suppression of enemy air defense (SEAD) assets in the immediate vicinity. Any weapons that took much more than 10 minutes to arrive would find the air defense platoon gone. SEAD aircraft could carry a variety of weapons, including ARMs that home on the radar emissions, Global Positioning System-guided weapons that fly to geographic coordinates, or visually guided weapons that image the radar either with a seeker on the missile or from other aircraft.

Taiwan determines the rate at which engagements occur between air defense platoons and ground-attack aircraft flights. The goal is to cause sufficient attrition to PLA aircraft so that they stop overflying Taiwan, staying out of AIM-120 range of defended areas. The Sentinel radar is the system at highest risk in the air defense platoon because missiles from supporting SEAD aircraft can target it. The number of missiles that are fired at them and the accuracy of those missiles drive Sentinel losses. The MMLs should be able to move very quickly once they are empty and are unlikely to be attacked.

Although short engagements followed by movement contribute most to survivability, a number of camouflage, concealment, and deception measures could also contribute in cost-effective ways to the IADS's survivability. Multispectral camouflage nets are becoming effective at obscuring targets from radar and electro-optical (EO) and IR sensors. In addition to hiding the systems, nets deployed over

⁷ Once targets are acquired, assume that, within five seconds of the Sentinel radar turning on, the air defense platoon begins launching AIM-120s from multiple MML vehicles at an average rate of one per second. The missiles accelerate to a top speed between Mach 3 and Mach 4 in six seconds. If the striker aircraft are 20 km away, the first missile reaches its target in 30 seconds. When firing two missiles each at four targets, the last missile arrives 43 seconds after the Sentinel radar turns on. The Sentinel radar can turn off 13 seconds earlier, 30 seconds after the Sentinel turns on, when the AIM-120 missile seekers have gone active and no longer require radar support.

false targets lower the chance of the weapon finding the right target. The air defense vehicles can be disguised or the MML missile tubes mounted on alternative vehicles. Multispectral smoke can obscure the target from weapon sensors at close range. The Sentinel radar could be mounted on a vehicle and driven to a prepared hide.

Disarming Strikes Vignette Analytic Results

To assess how long Taiwan's air defense platoons can survive and the attrition they can exact, we conducted a parametric analysis to calculate exchange ratios between attacking strike aircraft and the air defense platoons. We then used these exchange ratios to provide a measure of the sufficiency of the different options. These calculations provide insights regarding what Taiwan might expect to achieve with different levels of investment in air defense platoons.

The key variables in determining these exchange ratios between attacking aircraft and the IADS are the attacker's ability to geolocate an emitting defense radar, the speed of the attacking weapon (which will determine the number of shots against the weapon that the defender can take), and the weapon's end-game limitations. Having estimated these parameters (shown in Appendix B), we can calculate the probability of survival for the Sentinel radar and the number of engagements the defenders can sustain.

Although many SEAD weapons have antiradiation seekers that home in on the emissions from the engaging radar, the unique flexibility and common operating picture that is shared across the IADS through the IBCS allows a Sentinel radar that is targeted by weapons to turn off and give over to another radar guidance of interceptor missiles in flight. This means that the attacker will have to locate the emitting radar with some degree of error and launch weapons at that point on the ground because the radar will not be emitting long enough for the antiradiation weapon to reach it. The time difference of arrival (TDOA) or frequency difference of arrival (FDOA) geolocation technique can give a very fast and accurate location of the emitting radar but depends greatly on having several receiving aircraft in particular geometries with the radar to obtain the best accuracy. The accuracy of these systems can be very good (with an error less than 5 m) under

the most favorable conditions or quite bad (with an error greater than 1 km).

Another factor contributing to radar survival is the speed of the weapon used by the SEAD aircraft. This can range from Mach 4 for the LD-10 ARM, a variant of the PL-12 AAM, to Mach 1.5 for the YJ-91 ARM, to less than Mach 1 for the KD-88 EO-guided missile. As the weapons approach the Sentinel radar, the air defense platoon can fire its short-range interceptors (AIM-9X or a future smaller missile) to kill the attacking weapons. The air defense platoon will typically fire a volley of interceptors at the incoming weapons, see how many survive, and fire additional volleys as needed and time allows. The number of volleys is a very important factor. If one volley kills 90 percent of the incoming weapons, a fast weapon that allows time for only one volley would allow 10 percent of the weapons through, while two interceptor volleys would allow only 1 percent through.

Other factors also contribute to overall radar survivability. China would have a limited inventory of the different types of weapons, and the types carried by SEAD aircraft are unknown. Also, the number of SEAD aircraft that would protect each strike package is unknown; therefore, the number of SEAD weapons fired at the radar in an engagement is unknown as well. More importantly, in this vignette, these engagements are played out over a significant amount of time in which each side has the ability to adjust its behavior. If the defensive interceptors prove to have poor performance, Taiwan can fire more of them at each SEAD weapon. China could choose to package more SEAD aircraft on each mission. Both sides could attempt to limit engagements to those that best advantage themselves. Note, however, the changes that result in fewer air strikes by China are a benefit to Taiwan, above the aircraft shot down.

As prudent force planners, we choose SEAD performance numbers on the high end, ranging from 5- to 10-percent chance of killing the Sentinel radar per engagement. This represents an engagement by four fast LD-10 missiles, with the defender firing two volleys of medium- to poor-performance interceptors. Given these loss rates per engagement for the Sentinel radars, we can calculate how many engagements each air defense platoon could, on average, make before

losing a radar. For loss rates from 5 to 10 percent, this ranges from ten to 20 engagements.

Because each air defense platoon engagement can result in PLA aircraft losses, we can calculate an exchange ratio for each Sentinel radar in terms of aircraft killed. Like in other calculations, the number of aircraft killed in an engagement greatly depends on many factors that are not well known or cannot be discussed in this document. If Taiwan can pick its engagements carefully, the AIM-120 missile could be quite effective. A platoon engaging a four-ship of aircraft in the heart of its missile envelope could plausibly kill several aircraft. If we assume a range of one to two aircraft killed per engagement, assuming that each radar can survive ten to 20 engagements, the exchange rate would vary from ten to 40 aircraft per radar. Table 3.1 shows the effectiveness of different numbers of air defense platoons devoted to defending against PLA attacks in the Disarming Strikes vignette.

Taiwan's goal in this vignette is to cause enough attrition to force China into making air-to-ground attacks from standoff ranges. The winner in this contest is determined by which side reaches its limits first: Taiwan in the number of Sentinel radars it can lose and still have enough available for an invasion, and China in the number of aircraft it is willing to lose before stopping overflight of Taiwan. In the Disarming Strikes vignette, the number of Sentinel radars is more pertinent than the number of platoons because the radars are much more likely to be killed than the MMLs, and the loss of the radar does not prevent the MMLs from one platoon being added to a different platoon. Although the threshold number of aircraft lost is unknown, we assume that China would stop direct overflight after losing 10 percent of its

Table 3.1
Air Defense Platoon Effectiveness

Air Defense Platoons	Radar Loss Rate (%)	Aircraft Killed	AIM-120s Needed
5	5	100–200	300–600
	10	50–100	150–300
10	5	200–400	600–1200
	10	100–200	300–600

total fighter inventory, or approximately 200 aircraft. Assuming that Taiwan fires three AIM-120s for each aircraft killed (see Appendix B), this requires 600 total missiles. Also assuming the radar exchange rates given above, Taiwan would lose between five and 20 radars. Thus, for this vignette, to shoot down on the order of 200 attacking aircraft, Taiwan would need the capacity to lose five to 20 Sentinel radars and use 600 AIM-120s while still maintaining a reserve that could be devoted to countering an invasion (addressed in the Invasion Air Defense vignette).

As is often the case in force planning, the uncertainty in these estimates is high. There is uncertainty surrounding the number of aircraft that need to be shot down, the inventory and effectiveness of the SEAD weapons, the interceptor effectiveness, Taiwan's ability to pick favorable engagements and China's to get favorable TDOA and FDOA geometries, the number of SEAD weapons fired, and other factors. Another consideration is that, because this vignette could play out over several to many months, the type of damage done to systems on both sides becomes important. Damage done to Sentinel radars through warhead fragments can, in many cases, be repaired. Damage done to PLA fighters is more likely to result in the complete loss of the aircraft. Equally important to these performance uncertainties is that this is a war with no fixed timeline. Both sides can choose to engage more or less frequently and can adjust their tactics as uncertainties are resolved.

Vignette 3: Invasion Air Defense

This vignette focuses on Taiwan's air defense capabilities to counter the PLA air and missile forces supporting an invasion. It examines a portion of a larger invasion scenario in which the PLA seeks to put enough forces on Taiwan to force a capitulation and change of government. The invasion involves substantial numbers of PLA ground forces, supported by air, maritime, space, and cyberspace capabilities.

The PLA uses heavy missile and air attacks against fixed TK I/II air defense sites, then launches pinning attacks to cut runways at air bases to prevent aircraft from launching. These are followed by sweeps

of fixed-wing aircraft to attack aircraft on the ground. The intent of these operations is to protect PLA ground forces from air attack, to create a permissive environment for PLA air power to support ground operations, and to allow air-to-ground operations unconstrained by defenses on Taiwan.

Taiwan fully mobilizes to resist the invasion with a range of ground, maritime, and cyber defenses. As was the case in the Disarming Strikes vignette, Taiwan seeks to maintain its air defense forces and prevent them from quickly being destroyed. However, in this vignette, Taiwan's entire air defense assets are employed. The purpose of this effort, though, is more focused in this case. Rather than simply seeking to exact attrition, as in the previous vignette, here Taiwan's mobile air defense capabilities are needed to survive so that they can support planned counterattacks against landed PLA forces.

In short, Taiwan's air defense assets need to be able to protect ground units from air attack during key operational periods. The landed invasion force must be defeated by the systems that attack ground forces—tanks, antitank guided missiles, artillery, helicopters—and the role of the IADS is to allow these forces to operate when they need to. Given unrestricted air superiority, the PLA could break up a counterattack by Taiwan's mechanized forces or shoot down Taiwan's attack helicopters that are engaging landing craft approaching the beach. The mobile air defense systems—Patriot/TK III, and air defense platoons—enables these attacks by clearing the airspace for specific windows of time that are driven by the action on the ground.

We emphasize that we assume that the Patriot PAC-3 missiles are not used to intercept ballistic missile attacks; instead their purpose is to shoot down PLA strike and ISR aircraft to enable other Taiwan forces to operate freely at critical times in the war. Most of the PRC's ballistic missiles in this vignette are fired to suppress air bases when the Patriots/TK IIIs are hidden. Rather than intercepting some ballistic missiles to enable some Taiwan aircraft to fly and shoot down PLA aircraft, the Patriot missiles are better spent shooting down PRC fighters directly. In other words, PLA strike aircraft can carry up to 8,000 kg of weapons several times each day, while a ballistic missile delivers 800 kg or

less a single time.⁸ This vignette examines the periods when Taiwanese air defenses work to actively keep airspace open to protect ground force maneuvers. Patriot/TK III units work with air defense platoons to protect a maneuver area with a combination of long- and medium-range missiles to engage aircraft, and short-range missiles to defend radars.

Because the investments in these options will be made over 20 years, force planners must also consider how new Chinese systems that are expected to enter service will change the analysis. Fighters with reduced signatures, such as the J-20, could be more difficult to engage with AIM-120s and therefore increase the number of engagements needed to kill the required number of aircraft. Higher-speed SEAD weapons would reduce the number of intercept opportunities for the air defense platoons and reduce the Sentinel radar survivability.

The Invasion Air Defense Vignette Analytic Results

In this vignette, we seek to calculate how many medium- and long-range air defense assets Taiwan would need for a given number of attacking aircraft flying against Taiwan, broken into two-hour periods.⁹

The number of PLA air bases within unrefueled fighter range of Taiwan limits the number of fighters flying at one time to about 600.¹⁰ Assuming that these fighters fly at a combat tempo of two sorties each day, China could generate 100 sorties every two hours over Taiwan. In addition, the PLA has more than 150 attack helicopters¹¹ that could sortie across the Strait, generating another 25 sorties every two hours. China is also deploying a range of UAVs with the ability to deliver PGMs against ground forces and, as importantly, direct artillery and MRLs that can also deliver precision-guided rounds.

After gaining air superiority, China could set up kill boxes over areas of Taiwan containing ground forces, similar to the way U.S. air forces operated in Operation Desert Storm. These boxes would contain

⁸ “Strategic Weapons Systems,” 2014.

⁹ Two hours is a reasonable length for an average PLA aircraft sortie in this theater.

¹⁰ Shlapak et al., 2009, p. 54.

¹¹ “Army,” *Jane’s Sentinel Security Assessment: China and Northeast Asia*, May 23, 2014.

fighter CAPs ready to attack any units that expose themselves, with feeder CAPs to the rear ready to replace aircraft that had expended their weapons. The United States proved this tactic to be very effective and was able to disrupt ground forces moving in the open to attack or withdraw.

The air defense platoons operate as they did in the Disarming Strikes vignette, but, rather than engaging opportunistically, they are held in reserve with the Patriot/TK III systems, and only when Taiwan chooses to open an operational window do they emerge. In this instance, *operational window* refers to a period in which the SAMs engage air targets in order to allow some other operation by Taiwan's forces, such as a counterattack. During this period, air defense platoons would engage, shoot, and move in rotation until the airspace out to 40 km is clear of fighters and UAVs. As in the Disarming Strikes vignette, we assume a 5- to 10-percent chance of the air defense platoon's Sentinel radar being killed during each engagement.

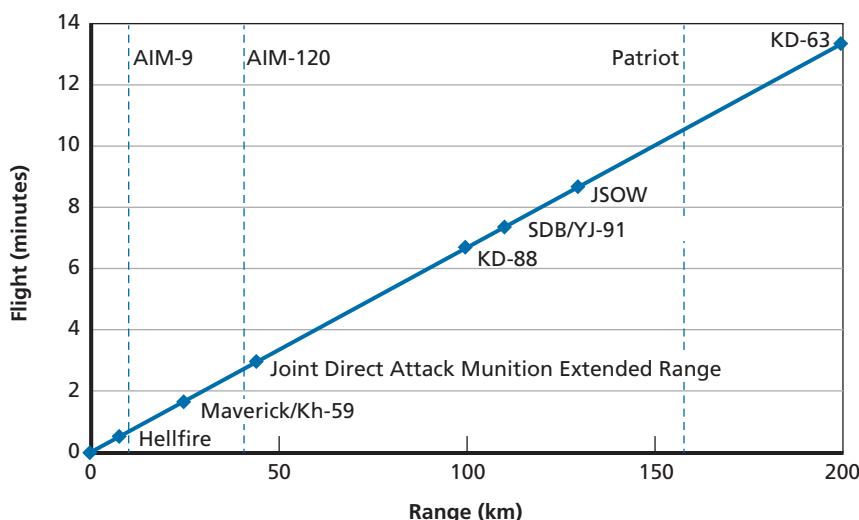
Although air defense platoons can engage aircraft out to 40 km, the long-range mobile SAMs (Patriot/TK IIIs) engage the supporting aircraft, such as those engaging in SEAD or electronic attack, as well as air-to-ground fighters in feeder CAPs. The threat of these long-range SAMs also serves to keep China's large ISR and command and control aircraft at a distance. Patriot/TK IIIs will be more challenged to survive, trying to empty their launchers and move before the PLA can target them with ballistic missiles and long-range MRLs.

Although it might be convenient to think of the sweeping of air-space as a complete elimination of air threats, it essentially creates a region of comparative safety in which the PLA is reduced to using longer-range standoff weapons that will have decreased effectiveness relative to the Taiwanese ground forces and will allow the ground forces to function in a militarily effective manner with a controllable number of losses.

As the aircraft are forced to stand off farther, the responsiveness of aircraft that are in a close air support role becomes difficult because the time of flight of the weapon increases the time it takes for the call for support to be answered, which also complicates coordination between the aircraft and ground forces. As range increases, the weapons avail-

able become increasingly expensive and therefore are usually in inventory in smaller numbers. As Figure 3.13 shows, the AIM-9 outranges an anti-armor weapon, such as the Hellfire. Medium- and long-range air defenses protect ground forces from air attack by increasing the time of flight of weapons and the cost of these weapons. Although air attack with PGMs can devastate mechanized forces, the worst losses are in cases in which weapons, such as laser-guided bombs, are dropped and directly targeted by aircraft or in which area-effect weap-

Figure 3.13
Comparing Threat and Defender Ranges



SOURCES: Kelvin Wong, "JDAM ER Performance Detailed During Latest Trials in Australia," *Jane's International Defence Review*, February 26, 2015; "Luoyang Opto-Electro Technology Development Centre (LOEC) LD-10," *C4ISR and Mission Systems: Air*, January 18, 2013; "AGM-114 Hellfire and Longbow Hellfire," *Jane's Air-Launched Weapons*, April 4, 2014; "GBU-39/B Small Diameter Bomb (SDB I), GBU-39B/B Laser SDB," *Jane's Air-Launched Weapons*, December 1, 2013; "Kh-59 (AS-13 'Kingbolt/Ovod)," *Jane's Strategic Weapon Systems*, May 12, 2014; "KD-63 (YJ-63, K/AKD-63)," *Jane's Air-Launched Weapons*, January 28, 2014; "AGM-154 JSOW (Joint Standoff Weapon) and JSOW-ER," *Jane's Air-Launched Weapons*, April 29, 2013; "AGM-65 Maverick," *Jane's Air-Launched Weapons*, March 18, 2013; "AIM-9X Sidewinder (Block I, Block II)," *Jane's Air-Launched Weapons*, July 18, 2013; "YJ-91, KR-1 (Kh-31)," *Jane's Air-Launched Weapons*, November 26, 2013; "KD-88 (K/AKD-88)," *Jane's Air-Launched Weapons*, August 19, 2013.

NOTE: JSOW = joint standoff weapon. SDB = small-diameter bomb.

ons, such as wind-corrected munition dispensers, are dropped from short-enough distances that the vehicles cannot easily evade them. The 40 km-range AIM-120 missile denies the use of the shortest-range optically guided missiles, such as the Maverick and the PLA Kh-59. Outside of AIM-120 range, large Global Positioning System-guided glide weapons with a time of flight of nearly three minutes, such as the Joint Direct Attack Munition, can no longer effectively attack moving vehicles. Although longer-range optically guided missiles, such as the KD-88, outrange the AIM-120, they have more than a six-minute time of flight, which gives vehicles time to move behind obstacles or take other protective measures if warned.

In the vignette, when the IADS engages, it might see 25 ground-attack fighters orbiting overhead, based on the allocation of fighters into 50 percent ground attack, 25 percent SEAD, and 25 percent air superiority. Over the Strait are another 25 ground-attack fighters in feeder CAPs, 25 SEAD aircraft, and 25 air-superiority aircraft. Without any details on the PLA's UAV inventory available, we assume that there are also 25 UAVs in orbits. During the two-hour period, 25 attack helicopter sorties will also be flown.

If the fighter sorties were apportioned in this way, they would have the capacity for two hours to attack a ground force that exposed itself by maneuvering. Kills per sortie of one or more armored vehicles are plausible using PGMs in this circumstance. This would result in the loss of more than 100 armored vehicles and would be a crippling blow to a Taiwan army operation involving several mechanized brigades in proximity to enemy ground forces.

With this level of PLA threat, the air defense platoons are responsible for engaging 25 aircraft, 25 UAVs, and 25 helicopters, while the Patriot/TK III batteries will engage the 25 feeder CAP aircraft, 25 SEAD aircraft, and 25 air-superiority aircraft. This number of aircraft, UAVs, and helicopters will enter the airspace every two hours.

The requirements for the air defenses are then to engage or drive off all of the aircraft that are threatening ground forces, to cover enough territory to protect the ground force maneuver operation, and to survive long enough to protect the number of operations that are needed.

In Appendix B, we show that several Patriot/TK III batteries must engage to have enough ready missiles to attack the 75 targets over the Strait. These long-range SAMs easily cover all of Taiwan. We credit the Patriot/TK IIIIs as having equal effectiveness against aircraft; however, there could be some differences. The one difference we do incorporate in our analysis is in the number of ready missiles of the two systems. The PAC-3 launchers have 12 ready missiles, while the TK III have only four. The primary consequence of this is that an individual Patriot PAC-3 launcher is able to engage promptly three times as many targets. Attrition to the Patriot/TK III radars is determined by the PLA's ability to target them with ballistic missiles, MRLs, or long-range artillery before they can move away. Although the PLA's ability to beat this timeline is unknown, it is plausible that the PLA could accomplish this if it chose to. We therefore make a generic assumption that the Patriot/TK III batteries suffer 50 percent or 75 percent attrition of their engaged radars during these two-hour periods of conflict.

For those options with air defense platoons, we devote 12 platoons to cover landing and maneuver corridors in both north and south Taiwan during a two-hour period. These platoons have more than enough ready missiles to engage the 75 targets over Taiwan. Attrition to the air defense platoon radars is determined by the number of SEAD weapons fired at them. We assume that 25 SEAD aircraft will be in the air, so we divide these into six SEAD packages that shoot four missiles each at six Sentinel radars.

In addition to holding at risk fixed-wing aircraft, the air defense platoons play an important role in disrupting PLA attack helicopter, UAV, and airborne operations. During the windows in which ground forces are maneuvering, they can be attacked and disrupted by attack helicopters flying across the Strait and by MRLs and regular artillery that are cued by UAVs. Taiwan's baseline IADS lacks survivable medium-range air defenses that can attack helicopters before they get into range to fire weapons, or attack UAVs before they get within sensor range of ground forces. Airborne transports would also be extremely vulnerable to air defense platoons and would likely be unable to drop airborne forces or land in any defended area.

Operational windows would be needed during each wave of amphibious landing and when defenders mount counterattacks against landed forces. During the amphibious landing operation, Taiwan's helicopters and artillery need air cover so that they can attack landing craft and amphibious vehicles as they approach the beach. Our RAND colleagues estimate that a plausible invasion force could be transported in two amphibious lifts with China's current fleet, each of which could take up to five hours to land.¹² This would require air cover for two six-hour periods. If the amphibious forces that land are halted, another window is needed to launch a counterattack by Taiwan's mechanized brigades. Other work by these RAND authors suggests that an attack of this scale would resolve in about 12 hours, or six two-hour periods. Adding up these two amphibious and one counterattack operations would require a total of 12 two-hour windows. Table 3.2 shows the total requirements, including estimates of radar attrition (see Appendix B). It shows that 21 to 26 Patriot/TK III radars and 16 to 20 Sentinel radars are needed to achieve 12 two-hour windows.

These numbers assume a sustained sortie rate of two per day, but air forces have historically bettered that rate for some number of days at the start of a war, and sorties can be shifted during a day to surge at

Table 3.2
Radar Requirements for 12 Two-Hour Windows over Taiwan

Radar	Needed in Window	Attrition per Engagement (%)	Radars Lost	Total Needed
Patriot/TK III	2–4	50	19	21
		75	24	26
Sentinel	12 ^a	5	4	16
		10	8	20

NOTE: This shows the radar demands to create 12 two-hour windows of cleared airspace over all of Taiwan, facing 100 fighter aircraft, 25 attack helicopters, and 25 UAVs every two hours.

^a Recall that only six Sentinel radars are attacked by SEAD aircraft each window.

¹² Shlapak et al., 2009, p. 109.

the times most needed. To reflect this, we consider cases in which the number of sorties is 50 percent higher, requiring the Patriot/TK III batteries and air defense platoons to each engage 75 targets. This increases the number of Patriots/TK III batteries needed to have enough ready missiles to attack the larger number of aircraft. Because the area needed to cover drives the number of air defense platoons needed, this number remains the same. However, the increased number of SEAD aircraft will increase the Sentinel radar losses. Table 3.3 summarizes these numbers.

Finally, although an ability to open 12 two-hour windows is a reasonable planning factor, if planners in Taiwan wanted to be able to sustain longer periods, they would not need to increase the number of covering SAMs but would need to allow for more radar losses because additional threat aircraft would present and need to be engaged over time. Table 3.4 shows the radars needed to open 18 two-hour windows.

The 57 F-35Bs in the JSF-Only Force structure option lead to a change in tactics for both sides. The JSF STOVL capability makes it nearly impossible to prevent sorties by attacking runways, so the PLA in this option would not expend these ballistic missiles. On the other hand, 50 JSF STOVL aircraft would not be able to prevent the PLA from gaining air superiority over Taiwan by themselves. We assume that the JSF STOVLs disperse and hide on the ground and wait to fly

Table 3.3
RadarS Needed for 150-Percent Sortie Surge

Radar	Needed in Window	Attrition per Engagement (%)	Radars Lost	Total Needed
Patriot/TK III	2-6	50	22	24
		75	30	32
Sentinel	12	5	6	18
		10	11	23

NOTE: This shows the radar demands to create 12 two-hour windows of cleared airspace over all of Taiwan but with the PLA being able to generate 50 percent more sorties than in Table 3.2. So Taiwan faces 150 fighter aircraft, 38 attack helicopters, and 37 UAVs every two hours.

Table 3.4
Radar Needed to Increase Window Duration by 50 Percent

Radar	Needed in Window	Attrition per Engagement (%)	Radars Lost	Total Needed
Patriot/TK III	2–4	50	23	25
		75	31	33
Sentinel	12	5	6	18
		10	11	23

NOTE: This shows the radar demands to create 18 two-hour windows of cleared airspace over all of Taiwan, facing 100 fighter aircraft, 25 attack helicopters, and 25 UAVs every two hours.

sorties in cooperation with Taiwan's long-range SAMs to open the windows of cleared airspace.

With no air defense platoons in this force structure option, the Patriot/TK III batteries would engage the PRC fighters over Taiwan to allow the JSF STOVLs to take off to engage aircraft over the Strait. However, the Patriot/TK III radars would suffer a high rate of attrition from aircraft-launched SEAD weapons in addition to other attacks and would be largely destroyed after seven two-hour engagement cycles. This would force the remaining JSF STOVLs to take off and land while under attack and would lead to their rapid destruction on the ground.

To assess the implications for how the force structure options would be able to cope with these three different demand levels, we have separated the radar demand from the interceptors. First, turning to the radars, Table 3.5 shows the number of radars in each force structure option and how much of the required range they satisfy. For the Baseline option, which has no air defense platoons, we assume that double the number of Patriot/TK III batteries would have to engage in each two-hour window and that these would suffer 90 percent attrition from the combined aircraft SEAD and ballistic missile attacks. Under these conditions, almost no number of Patriots would be sufficient. In the JSF-Only Force structure, the ability of the JSF STOVLs to fly while protected by the Patriot/TK III batteries allows the origi-

Table 3.5
Radar Sufficiency in the Force Options

Force Structure Option	Patriot/TK III Radars		Sentinel Radars	
	Number	Percentage of Required	Number	Percentage of Required
Baseline	21	<50	0	0
Mixed Force	25	80–120	42	180–260
JSF-Only Force	21	60–70	0	0
SAM-Dominant Force	34	100–160	80	350–500

NOTE: This shows the ability of each option to satisfy radar demands of the Invasion Air Defense vignette. For the Mixed Force and SAM-Dominant Force options, the lower bound is the demand to create 12 two-hour windows of cleared airspace over all of Taiwan, while suffering 50 percent attrition facing 100 fighter aircraft, 25 attack helicopters, and 25 UAVs every two hours. The upper bound is the demand to create 18 two-hour windows of cleared airspace over all of Taiwan while suffering 75 percent attrition. For the Baseline and JSF-Only Force options, without air defense platoons, which have two radars each, the attrition rate is 90 percent.

nal number of SAMs to engage, but these again suffer a high attrition because of the lack of air defense platoons.

The Mixed Force and SAM-Dominant Force options have sufficient Sentinel radars for the baseline, sortie surge, and increased window contingencies of the Invasion Air Defense vignette. The SAM-Dominant Force option meets the Patriot/TK III radars needed for all the contingencies and has more than half again the requirement in the most optimistic cases. Although the Mixed Force option meets the most optimistic requirements, it fails in more-difficult circumstances. The options without air defense platoons suffer extremely high Patriot/TK III radar losses.

In considering interceptor missile totals, both the Patriot/TK III batteries and air defense platoons need to engage a total of 600 to 900 aircraft in their respective airspaces during the 12 to 18 two-hour periods in this vignette. If two missiles are fired at each maneuvering target and one at each UAV, this would require 1,000 to 1,500 AIM-120 and 1,200 to 1,800 Patriot/TK III missiles for those options that have a layered defense. Those options that did not invest

in air defense platoons (the Baseline and JSF-Only Force options) place a greater demand on the Patriot/TK III systems to compensate. They would have to attack all the targets, which increases the total demand to 2,200 to 3,300 Patriot/TK III missiles. In reality, this option does not have a meaningful missile requirement because their radars would be killed long before they could shoot all of those interceptor missiles. Fewer missiles would be needed in the JSF-Only Force option because the JSF STOVLs would initially attack half the targets, but again the Patriot/TK III radars are quickly killed without the presence of defending air defense platoons. The Mixed Force and SAM-Dominant Force options have sufficient Patriot or TK III missiles and AIM-120s. Table 3.6 shows the missiles available in each option and the fraction of the required range of demands to create 12 two-hour windows.

The defender's ability to keep attrition in check is closely tied to the tactics that the defense employs. The analysis presented here presumes that the defender would employ tactics designed to mitigate threats from attack but that the defender would nevertheless need to be up and exposed to the enemy forces for significant periods of time. Some possible tactics, such as blinking radars and moving frequently, would help moderate losses, but it is our expectation that most losses

Table 3.6
Interceptor Missile Sufficiency in the Force Options

Force Structure Option	PAC-3/TK III Missiles		AIM-120 Missiles	
	Number	Percentage of Required	Number	Percentage of Required
Baseline	1,503 ^a	Radar limits	0	—
Mixed Force	1,803	100–150	2,100	140–210
JSF-Only Force	1,503	Radar limits	0	—
SAM-Dominant Force	2,471	140–210	1,600	110–160

NOTE: This shows the ability of each option to satisfy the interceptor demands to create 12 to 18 two-hour windows of cleared airspace over all of Taiwan, when facing 100 fighter aircraft, 25 attack helicopters, and 25 UAVs every two hours.

^a Appendix B discusses the assumptions for Patriot and TK missile inventories.

come in the period immediately after the initial turn-on of the radars from the most proximate reactive threats. Although snap-shots (that is, shoot-and-move maneuvers) at the enemy aircraft might be possible with little risk, the need to engage and really clear airspace means that counterattacks will occur. Nevertheless, appropriate tactics will help greatly against forces that come from greater distances and could be useful in defeating the attacks directed at the radar. The magnitude of the benefits is difficult to estimate in this forum and is quite dependent on a host of factors.

Demands for Defenses in Sequential Vignettes

So far, we have considered each vignette in isolation. However, a future conflict could begin with coercive attacks that served as a prelude to an invasion. If Taiwan chooses to size its force to have a capacity to cope with a sequential attack that unfolds with engagements resembling the Disarming Strikes vignette initially, followed by an invasion requiring windows of opportunity addressed in the Invasion Air Defense vignette, the options can be considered as follows. Table 3.7 lists the options that have air defense platoons and how close they come to satisfying the requirement to meet these sequential vignettes. Patriots/

Table 3.7
Ability of Options with Air Defense Platoons to Cope with Sequential Vignettes

Force Structure Option	Air Defense Platoons	Sentinel Radars		AIM-120 Missiles	
		Number	Percentage of Required	Number	Percentage of Required
Mixed Force	21	42	110–200	2,100	100–130
SAM-Dominant Force	40	80	200–380	1,600	80–100

NOTE: This compares the sufficiency of options with air defense platoons to meet the goal of having the capacity to shoot down 200 aircraft in the Disarming Strikes vignette (five to 20 radars plus 600 missiles), plus the capacity derived from the Invasion Air Defense vignette analysis to create 12 two-hour windows (16 to 20 radars and 1,000 to 1,500 missiles).

TK IIIIs are not used in the Disarming Strikes vignette, so the demand for those assets from the Invasion Air Defense vignette is the total demand shown in Tables 3.5 and 3.6.

The options without air defense platoons are clearly inadequate because the Patriot/TK IIIIs would have to fill the role of both long- and medium-range air defenses without the protection of the air defense platoons. The Mixed Force option is short Patriot/TK III radars under pessimistic assumptions but has sufficient AIM-120 missiles, and otherwise meets requirements. The SAM-Dominant Force meets the Patriot/TK III radar and missile requirement under all conditions, has sufficient Sentinels, and is short AIM-120s under pessimistic assumptions.

Table 3.7 shows the demands to create 12 two-hour windows. However, Taiwan would have to do an assessment to determine the desirable number of windows. To give a sense of how this might scale, we calculate that, with the pessimistic attrition assumptions, to create 18 two-hour windows or cope with PLA surges, Taiwan would need about 43 Sentinel radars, 2,100 AIM-120 missiles, 33 Patriot/TK III radars, and 1,800 PAC-3/TK III interceptors. Because Taiwan has already invested in 21 Patriot/TK III batteries and 1,500 missiles, meeting this demand would require an additional investment of 12 Patriot/TK III radars and 300 missiles, assuming that the Patriot/TK III batteries are equally effective in this role against current threats.

In the Air Sovereignty vignette, we considered the implications of new PLA systems, such as the J-16. Most of the advances for that system come from its air-to-air weapon and combat systems. This PLA advance will not change the SAMs' effectiveness because the J-16 radar signature will not meaningfully differ from those of current systems. When China can field aircraft with smaller RCSs, it will drive up demand for SAM radars and interceptors in both the Disarming Strikes and Invasion Air Defense vignettes.

Concluding Thoughts on the Vignettes

These three vignettes span a set of air defense missions that are representative of the kind of missions Taiwan should be considering in shaping and sizing its air defense forces for the future. With these vignettes, we have explored the performance of current and possible future Taiwan systems, as well as current and future PLA capabilities. The analysis showed gaps and imbalances in Taiwan's current capabilities.

The analysis of the Air Sovereignty vignette showed that current PLA fighter capabilities have surpassed the current fighters. It also showed that upgrading to more-advanced fighters is costly and that Taiwan cannot modernize and keep both costs and fighter numbers constant. Either the budget will have to increase, or Taiwan will need to reduce the number of fighters it has. Beyond the question of the appropriate number, the analysis highlights the limited potential of fighters in future conflicts with China.

This chapter also highlighted gaps in the SAM force. In particular, Taiwan's medium-range air defenses need modernization to cope with the increased air threat and to complement longer-range systems, such as the Patriot/TK IIIIs. Adding a modern medium-range system, such as the air defense platoons examined here, complements the investments made in longer-range systems.

The vignettes also reflect our conclusion that fighters are too vulnerable to ground attack to be able to play a decisive role in air defense under a very large attack of the kind that the PLA is now equipped to deliver. This makes a direct comparison of the utility of fighters and SAMs for Taiwan difficult because the systems play very different roles in response to the threat. Although we would have liked to be able to directly compare the effectiveness of SAMs and fighters in an invasion scenario, the poor survivability of the fighters makes such a comparison impractical. It would hinge on our assumption of how many sorties a fighter could make before being destroyed.

As we describe in this report, our assessment is that fighter aircraft could manage only a very small number of sorties in the face of PLA attacks directed at them while on the ground. Even if Taiwan were to hide some aircraft in caves and operate others from highway strips or

other nontraditional locations, if Taiwan attempted to generate sorties from such locations, the PLA would not take long to locate and target these locations. Thus, we would be comparing the cost-effectiveness of a few total fighter sorties. SAMs suffer attrition too. What is different is that the SAMs are sized to account for this attrition, and Taiwan can choose when to operate the SAMs. Because both the SAMs and the fighter aircraft would be enabling capabilities, retaining the choice of when to employ them is a key advantage SAMs have over fighters.

This assumes a very committed attack on the part of the PLA. Some might argue that a coercive scenario is more likely and thus should command more resources. The likelihood of an event should not be the dominant consideration in military planning. Although coercive scenarios certainly should be considered more likely, an invasion poses the gravest existential threat. If a coercive scenario is attempted and fails, Beijing might not be willing to halt military operations and settle for a setback. It is usually assumed that one must have escalation dominance in order to be successful in a limited conflict scenario. Taiwan does not have escalation dominance, so an emphasis on countering coercive scenarios to the detriment of capabilities against more-direct attacks might not serve it well.

Implications

The results of our analysis suggest that Taiwan should consider a fairly radical change in how it might approach air defense by doing the following:

- downsizing and shifting its fighter aircraft force to focus on coercive scenarios
- increasing its investment in SAMs
- dedicating its surface-based air defense to becoming an enduring warfighting capability that can contribute throughout the duration of a sustained and effective defense of Taiwan.

Although this does not represent a traditional allocation of airpower, adversary capabilities force Taiwan to substantially restructure and rethink its air defense. The fighter force's inability to contribute effectively following a sustained and powerful missile and air attack on its bases and operating infrastructure, as well as performance of its force in high-intensity coercive air encounters, together make very large investments in fighter aircraft unlikely to prove particularly potent in the future. In contrast, the plausible range of performance of a properly equipped and well-trained SAM force suggests that these air defense forces could prove very influential in higher-intensity campaigns in which Taiwan has to contest air sovereignty. This chapter explores some force-sizing approaches for Taiwan's fighter aircraft and SAM forces tied to operational demands derived from the vignettes in the context of Taiwan's overall defense resources.

Taiwan's force structure is evolving to look like the Baseline force, and we estimate that the current force will cost US\$22 billion over the next 20 years in operations and maintenance expenses, plus US\$3.3 billion to retrofit its F-16A/Bs. Unfortunately, by the time the retrofit can be completed, the PLA will already field more advanced fighters. The question is what the best use is of this more than US\$25 billion in potential spending in order to improve Taiwan's air defense capabilities given a rapidly evolving threat. An inquiry to answer this question should begin by considering the demand for SAMs.

Sizing the Surface-to-Air Missile Force

The size and characteristics of Taiwan's surface-based air defenses are closely tied to their ability to meet a wartime need to defend forces in the field in the face of substantial air and cruise missile threats. In the Invasion Air Defense vignette, we showed how a layered air defense system that combined Patriot/TK III batteries with shorter-range air defense platoons brought out the strengths of both types of SAMs. The Patriot/TK III systems have radars and interceptors that hold aircraft flying over a wide area at risk. Patriots/TK IIIs operating from three or four general areas could threaten adversary aircraft in Taiwan airspace at medium or high altitude. (The number of operating areas is dictated by terrain blockage concerns and ensuring that SAMs are not operating at the extremes of their operational range.) The air defense platoons have much shorter ranges. For instance, the effective range of an AIM-120 is about 40 km, so assessing the demand will depend on the desired geographic areas that Taiwan might want to cover, in addition to consideration of its performance against potential threats, which was the focus of the analysis in Chapter Three. In this discussion of force sizing, we summarize those findings but also add consideration of the geographic coverage Taiwan might want from its SAM systems.

Taiwan's SAM forces will need to have the following to defend the ground forces from air attack:

- sufficient numbers to sustain operations for operationally relevant time periods to support defensive operations of other units, such as ground forces
- adequate coverage of major maneuver areas, with enough concentration to survive multiple engagements over the course of the conflict
- SAM radars spatially distributed to cover low-altitude holes relevant to defense of the forces
- SAMs close enough to support each other and allow for appropriate tactics to maximize lethality and survivability.

Some maneuverability of Taiwan's defense forces is likely to be an important factor in defense, but, without protection from air defenses, such movement would likely turn out very badly. In contrast, dug-in or halted forces would be expected to disperse; use camouflage, concealment, and deception; exploit opportunity for cover and passive protection (natural and constructed cover); and need only modest protection from active defenses to limit the amount of damage from air attack.

The coverage will not be uniform across all of Taiwan but will favor areas where the army is likely to operate. In looking at Taiwan, we see regions where ground defenses might be able to play effectively in the roles outlined above, particularly over beaches suitable for amphibious landings and ports that could be used to insert forces. A more expansive requirement might seek to cover the entire western coastal plain because much of the rest of the island is mountainous and not well suited to exploitation by large ground forces. The ability to defend airspace over potential landing zones would support immediate responses by Taiwan's ground force, while a force sized to defend the entire coastal plain could support more-extensive defensive movements of Taiwan's forces both toward battle and attempting to disengage from a battle.

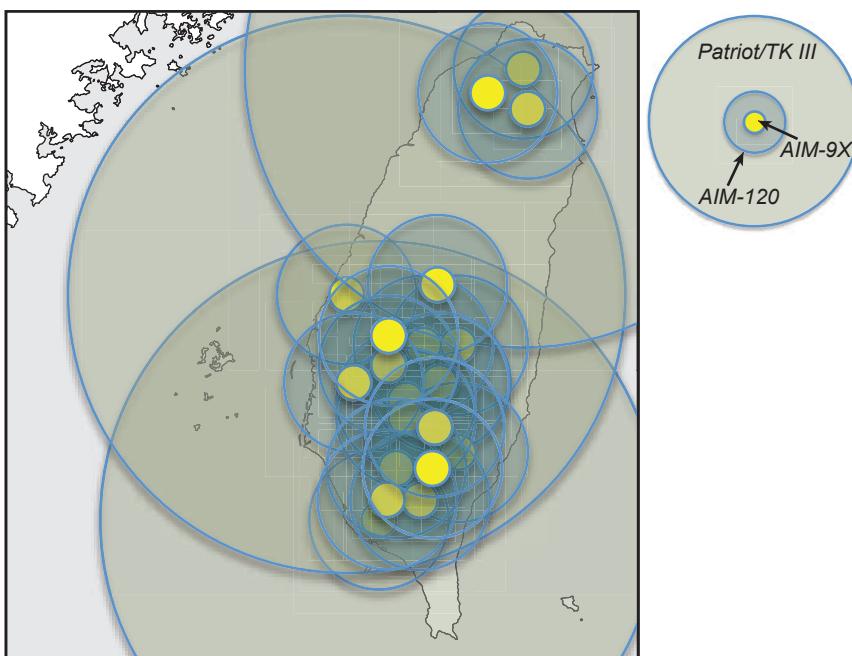
In Chapter Two, we showed how Taiwan might be able to afford 21 air defense platoons, and another option that would allow an invest-

ment of up to 40 air defense platoons, depending on the level of Taiwan's divestment from its current fighter aircraft. Each air defense platoon has two Sentinel radars to enhance survivability. Turning now to their geographic coverage, we see that Figure 4.1 illustrates that a force of 21 air defense platoons covers much of Taiwan's western coast and could be considered adequate for defending likely landing zones and ports. A force of this size was shown in Chapter Three to be sufficient to contribute sequentially to defending Taiwan against coercive attacks and still retain the capacity to fulfill its mission in an invasion. Because the PLA easily has the force structure to attempt to intimidate Taiwan, as is the goal in the Disarming Strikes vignette, and still retain the forces to launch an invasion, Taiwan should consider sizing its air defense forces to also be able to defend Taiwan from such a sequence. A force of 21 air defense platoons could conduct both vignettes sequentially, even if we assume attrition were high. It is also important that these forces have sufficient AIM-120 missiles in order to complete their mission. We estimate they would need between 1,600 and 2,100 to sustain operations through both the Disarming Strikes and Invasion Air Defense vignettes. All told, this would require an investment between US\$8.1 billion and US\$9.2 billion; the lower figure is near the cost to retain 127 F-CK/IDF aircraft for 20 years.¹ Although this option is sufficient to sustain the operations called for in the two relevant vignettes, it would have some geographic limitations, as illustrated in Figure 4.1.

The force structure option that invests in 40 air defense platoons enables coverage of almost the entire coastal plain (Figure 4.2). It would provide Taiwan with considerable operational flexibility to provide both more-complete geographic coverage and the depth to sustain the defenses in some areas for considerable lengths of time, beyond just an immediate counterattack at the point, or points, of landing. Figure 4.3 compares how 40 air defense platoons might be available for an engagement either with all of them active to cover a large area

¹ This is the price for 21 air defense platoons (four MMLs, two Sentinel radars, one IBCS, and 80 AIM-9Xs per platoon). The variable is for the total number of AIM-120 missiles (1,600 to 2,100) to arm these platoons.

Figure 4.1
Geographic Coverage of 21 Air Defense Platoons and PAC-3s

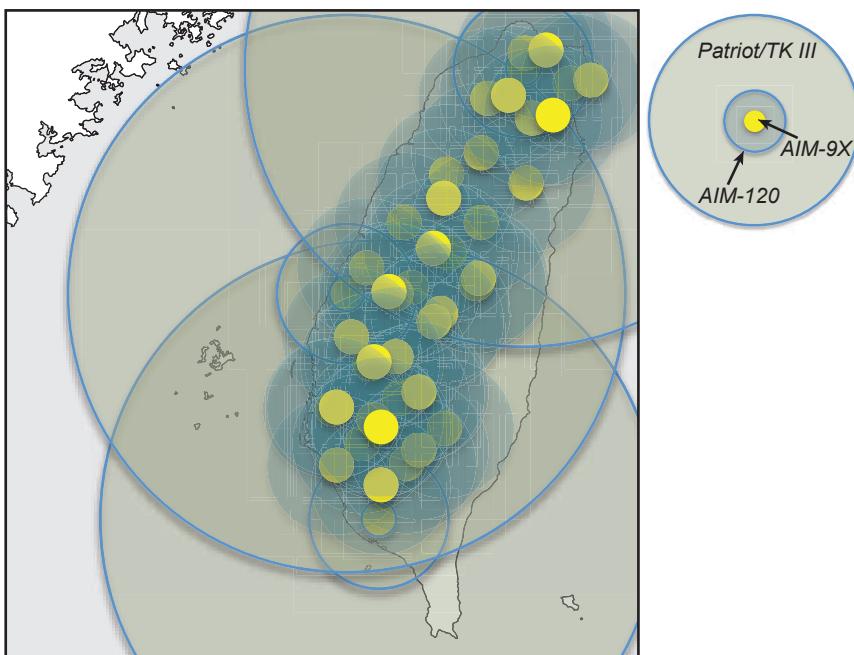


RAND RR1051-4.1

(left part of Figure 4.3) or with a deployment that allows for more-survivable operations involving unit activation, teardown, and relocation (right part of Figure 4.3). Note that, although the left part of Figure 4.3 has significant geographic extent, the coverage is much thinner, and the number of systems with overlapping coverage necessary for mutual protection is lower. This kind of defense would require an investment of US\$13.3 billion to reach 40 air defense platoons, which is about US\$1.7 billion more than Taiwan is projected to spend on its F-CK and Mirage fleets over the same time period.

The additional geographic coverage and depth of defenses would certainly be a benefit in operations. In particular, they would minimize the distance that air defense platoons would have to travel to protect maneuvering forces because much more of the island would be covered. They would still require tactical movement to avoid attacks. Although

Figure 4.2
Geographic Coverage of 40 Air Defense Platoons and PAC-3s

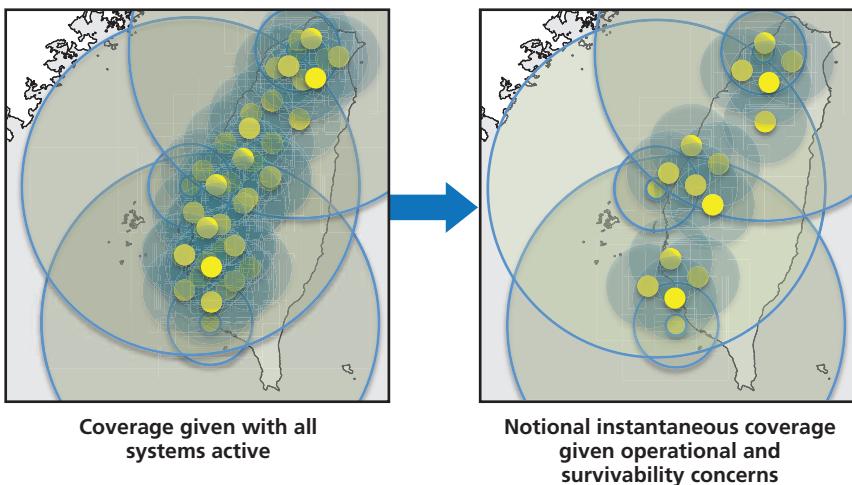


RAND RR1051-4.2

there are benefits to a force of this size, until other defense priorities are met, an investment of 40 air defense platoons would appear to be an overinvestment in this capability at this time.

Air defense platoons offer their highest leverage for Taiwan when coupled with longer-range systems, such as the Patriot/TK IIIIs, of which Taiwan already has a substantial force. In Figures 4.1 through 4.3, we show how three Patriot batteries can cover all of Taiwan, so the current force already meets geographic coverage needs. Future force sizing should focus on the number of radars and interceptor missiles needed to meet operational demands. Unfortunately, these are fairly vulnerable and high-value systems, making them a likely focus of PLA attacks. In our analysis, we assumed that they would suffer between 50 and 75 percent attrition when operating to clear two-hour windows of opportunity. Although these are movable systems, Taiwan should

Figure 4.3
Instantaneous Air Defense Coverage of Maneuver Corridor on the Coastal Plain



RAND RR1051-4.3

emphasize its need for greater mobility from these systems when it makes future investments in such capabilities. If the time it takes to tear down and move a Patriot battery, particularly the radar, could be substantially reduced, its survivability would greatly increase.

Patriot/TK III SAMs offer their highest leverage when coupled with medium-range systems that can effectively defend them from aircraft-launched SEAD weapons. Without this defense, we estimated that the combination of aircraft and ballistic missile counterattacks would result in nearly complete losses to these SAMs when they engage. Another consideration is that the overall rate of radar attrition drops as the number of PAC-3 missiles acquired rises. The SAM launchers can carry four TK III and PAC-2 missiles but 12 of the PAC-3 MSE missiles. As the proportion of PAC-3 missiles in inventory rises, the average number of ready missiles on batteries rises, and fewer batteries are needed to clear the airspace of targets.

In sizing the SAMs, we sought to meet a goal of creating 12 two-hour windows of opportunity above Taiwan and assumed attrition

rates of 50 to 75 percent. We then examined two more demanding drivers: an increase in the number of windows to 18 and an increase in the number of threat aircraft consistent with a 150-percent surge. Our calculations of the resulting demands assume that the air defense platoons are acquired and operate with the Patriot/TK III systems to form a layered defense. Taiwan's planned inventory of nine Patriot and 12 TK III batteries is sufficient to create 12 two-hour windows. If Taiwan invested US\$4 billion in five additional Patriot batteries and 300 PAC-3 missiles, it satisfies requirements if radar attrition is low, even in the cases in which the sortie rate or the number of windows needed is larger. However, it is short in cases in which the radar attrition rate is high. The addition of 12 Patriot batteries and 300 missiles is enough to satisfy the requirements in the most pessimistic case and would cost US\$10.6 billion.² Table 4.1 summarizes these options. The Mixed Force structure added four new Patriot batteries and 300 PAC-3 missiles. This mix is sufficient for the most optimistic case,

Table 4.1
Patriot/TK III Force Sizing

New Patriot/ TK III Batteries	New Interceptor Missiles	Cost (millions of BY 2013 US\$)	Capability
0	0	0	12 two-hour windows, 50% attrition
5	300	4,002	12 two-hour windows with 75% attrition, or, with 50% attrition, 18 two-hour windows or 50% sortie surge of PLA fighters
12	300	10,686	18 two-hour windows, or, with 75% attrition, 50% sortie surge of PLA fighters

NOTE: This assumes that the Patriot/TK III batteries are combined in a layered defense with 21 air defense platoons. It also assumes a current inventory of 21 Patriot/TK III batteries and 1,500 Patriot/TK III interceptors. The table indicates the additional Patriot batteries and interceptor missiles to achieve the capability goals of the final column.

² That is enough to open 18 windows of opportunity facing the PLA 150-percent surge and assuming 75 percent attrition.

with 12 windows and 50 percent radar attrition, but falls short if any assumption is more pessimistic. The SAM-Dominant Force structure with 13 new Patriot batteries and 975 PAC-3 missiles has somewhat more radars and missiles than are needed for even the pessimistic cases.

The choice among these three levels of investments in Patriot/TK III batteries rests on both Taiwan's calculations of how many windows of opportunity it will want to create and what assumptions it has about radar survivability. Because the SAMs are enabling forces, the number and duration of the windows depend on the operations they are supporting and the assumptions about their duration. By showing these three levels of investments and the amount of protection they can provide under two different attrition assumptions, we give a sense of the scale of investment.

Sizing the Fighter Force

The selection of the type and number of fighter aircraft is typically extremely complex, with many factors influencing final choices. Unfortunately for Taiwan, the imbalance in the future with the PLA is going to be especially severe, so it actually simplifies the problem to a significant degree.

Taiwan's fighters cannot sustain operations against the threats that China now offers, unless operations are constrained, as they would be in coercive scenarios. In the future, this will only get worse with the introduction of advanced "stealthy" fighters, such as the J-20 and potentially J-31, as well as improved air-to-air weapons. There is a trio of problems facing fighter aircraft based on Taiwan: multiple threats to aircraft on the ground at air bases, unfavorable force ratios in the air, and erosion of any qualitative advantage in the air. These problems suggest a shift in focus away from selecting and sizing the fighter force for the most violent campaigns depicted in the Invasion Air Defense vignette and instead toward focusing on the role of fighter aircraft in low-intensity coercion scenarios, such as that examined in the Air Sovereignty vignette.

In high-intensity coercion or invasion scenarios, the survivability of the SAMs makes them a clearly preferred option to contest Taiwan's airspace. Fighters have certain advantages over SAMs in coercive scenarios that involve very limited uses of force. For instance, a fighter can be used to intercept and challenge a potential hostile aircraft. It provides an option for positively identifying targets with visual inspection that SAMs cannot provide and a more measured means of determining intent of the unknown aircraft before the aircraft reaches a sensitive location. Once a fighter positively identifies an aircraft as hostile, it does offer at least a possibility of forcing that aircraft to land or return whence it came, but this would seem to be a fairly low-probability situation.

A truly hostile air threat, however, is unlikely to be diverted from its flight path or forced to land. Moreover, an "attack" with a small number of aircraft is an unlikely means for the PLA to strike targets on Taiwan. Alternatively, such attacks could be carried out from long range with probably equal effectiveness but with much less risk of loss.

If the PLA elects to fly aircraft over Taiwan early in a conflict, it is more likely to achieve some political objective: either a demonstration of Taiwan's military weakness, such that it must allow enemy fighters free rein within its airspace, or, more cynically, an early flyover to bait Taiwan into striking the first blow, which the PLA could then use to try and justify disproportionate military acts against Taiwan. In this case, having fighter aircraft intercept a more aggressive threat aircraft would allow Taiwan to be in position to act when it chooses against the threat aircraft, while the SAMs might not offer the continuous coverage that a respectable fighter force could provide. Furthermore, theoretically it might be possible for a threat aircraft to conduct a strike mission and egress in such a way as to avoid SAM coverage areas, thus denying Taiwan its opportunity for retribution. But if Taiwan were to make a large investment in its air defenses, of the kind proposed in the SAM-Dominant Force option, then gaps in SAM coverage against hostile aircraft will be fewer and less predictable.

Another limitation of SAMs is that they tend to have a reputation for forcing defenders to act quickly. In part, this is a fairly understandable behavioral response to the vulnerability of the system. As

soon as a SAM radar is turned on, it becomes exposed to attack; this vulnerability might make defenders quick to engage potential threats. The maneuverability of a fighter gives it the ability to evade a potential threat, but this goes only so far, depending on the adversary's capability and intent. There are also situations in which opposing fighters get so close to each other that the option to evade an AAM is lost.

Finally, fighters allow Taiwan to project power across much greater distances than SAMs can. For instance, part of the Air Sovereignty vignette involves protecting a SLOC that is beyond the range of SAM coverage. Having fighters would enable Taiwan to interdict hostile aircraft for hundreds of miles along a corridor east of Taiwan to protect ships bringing supplies to Taiwan in a blockade scenario. SAMs could contest only the airspace close to Taiwan's shores. Furthermore, fighter aircraft could assist in keeping hostile ships from approaching blockade runners east of Taiwan.

Although we characterize the advantages that fighters bring above, these do not provide very strong motivation to command air defense dollars, if defense against an invasion is of prime concern. In general, the survivability and effectiveness of SAMs will make them a first choice. Still, Taiwan might feel that it can afford some fighter capabilities. As discussed in Chapter Three, the level of force applied in the Air Sovereignty vignette is tailor-made for fighters. It involves enough force that the fighters contest airspace in air-to-air combat, but not so much force that the adversary seeks to destroy the aircraft on the ground before they can even launch to contest that airspace. Certainly, a 2v4 engagement is a very limited one. Both China and Taiwan could generate many more fighters than that, and it is imaginable that much larger engagements could occur; however, in practice, China can control how large such engagements are. If China does not want to meet Taiwan's forces in the air, its missiles could ensure that it does not. Thus, it comes to a judgment call by policymakers in Taiwan as to whether such a scenario is plausible and, if so, whether it justifies the investment in fighter aircraft to continue to have the capability to contest airspace far to the east of Taiwan to protect its maritime approaches.

Retaining some fighter force is possibly warranted if Taiwan wants to be able to contest pockets of airspace around Taiwan and to positively identify air threats and determine their intent, over a range of coercive type scenarios with a degree of control over when and how to engage relatively small numbers of air threats. But this comes with a substantial opportunity cost. If Taiwan is willing to have a somewhat more-limited air defense in both its geographic coverage and in terms of a slightly less flexible countercoercion option, mobile SAMs provide considerable capability against limited coercive threats. If Taiwan still wants the flexibility provided by fighters, the question, then, is how many it should operate. Given the limited scenarios for which fighters provide a clearly preferred solution, the current force of roughly 325 aircraft appears excessively large.

We think that the demands of the SAM force should take precedence over investments in the fighter force. However, for completeness and to satisfy those who might come to a different conclusion, we see two possible fighter sizing constructs: one that seeks to fill defensive fighter CAPs across all of Taiwan and another that uses a smaller number of more-capable fighter aircraft to intercept small numbers of adversary aircraft and provide some protection to a SLOC. Each of these relies on a fairly constrained use of force by the adversary.

Taiwan's current budget levels and political constraints might impede both of these options. Taiwan would have to increase its budget for its fighter force if it wants enough new advanced fighters to sustain defensive fighter CAPs continuously around the island. Without a budget increase, it would have to operate a mix of legacy and new fighters to keep the force large enough. If Taiwan wants to invest in the most advanced fighters available, it depends on the willingness of the United States to make such a platform available. A third option is to phase out the fighter force in favor of SAMs, which would not be an unreasonable response to a very difficult operational challenge that, in a few short years, has really turned the competition on its head, or keep only a small residual fighter aircraft force, as explored in Chapter Three.

The arrangement of fighter combat power into seven defensive CAPs, suggested in Chapter Three, is a doctrinal approach to air

defense that could be used to size the force, but Taiwan could certainly use other concepts to plan for and size its defense force. Filling all seven CAPs 24 hours per day would require 86 ready aircraft. Assuming that Taiwan can keep about 80 percent of its force operational at any time and that it wishes to continue to maintain some aircraft in the United States for training, using the seven CAPs as a force-sizing construct would lead to a minimum of about 130 aircraft. This is about the number of either F-16 or F-CK fleets currently in Taiwan's inventory. The F-16s, though, are less expensive to operate and are more capable.

Of the force structure options analyzed, the Mixed Force provides an example of a force structure that lends itself to implementation of the seven-CAP defense. It makes a fairly substantial investment in air defense capabilities, with 21 air defense platoons. Although it makes substantial cuts to the fighter aircraft force, it retains and retrofits 144 F-16s. Any choice that keeps more than about that total number of fighters begins to overinvest in a capability we see as marginal because of the limited types of situations in which a fighter aircraft is best suited to deal with threats to Taiwan from China. However, as we consider that, in the future, China's fighter force is likely to gain a qualitative edge over Taiwan's fighters, keeping 144 aircraft might misalign Taiwan's air defense investments by locking resources into a legacy system with major survivability challenges. Taiwan might be better off selling its F-16s to a country that does not face such advanced threats. In addition, as we saw in the assessment of the SAMs, the Mixed Force option possibly underinvests in Patriots to meet the more-ambitious and stressing cases (increasing windows of opportunity from 12 to 18, meeting a sortie surge, or suffering the most pessimistic loss assumptions examined).

Taiwan could elect to sustain fewer, more-capable, aircraft if it elected to use them differently. There are clearly some limitations to a concept that spreads out aircraft in pairs across Taiwan, as would be the case in the seven-CAP construct. It is a predictable defense, and it allows the attacker to mass forces against a small number of aircraft. An alternative concept would be to rely primarily on SAMs for air defense but to keep a smaller fleet of fighters to conduct the two kinds of missions at which they excel: intercepting small numbers of

potential adversary air threats that cross into Taiwan airspace in peacetime and, at the very beginning of a conflict, contesting airspace in the approaches to Taiwan in a blockade situation. The Mirage fleet, at 57 aircraft, currently offers somewhat fewer aircraft than this; however, it is the most expensive of Taiwan's current fleet to operate and not the most capable.

The report shows that, under current budget constraints, a small force of 57 JSF displaces all the existing fighters and leaves no resources for SAMs. We assessed it to be very capable in the air against the PLA's current force; however, it remains vulnerable to attack while on the ground. To keep within the same budget levels and afford both JSF and SAM investments, a force of 42 JSF would allow for more than a US\$8 billion investment in SAMs. This would allow Taiwan to invest in 21 air defense platoons, including 1,600 AIM-120 missiles. This could meet many of the SAM needs while giving Taiwan an ability to contest something like the Air Sovereignty vignette for about two and a half weeks against the upgraded J-11B armed with PL-15 missiles. A large uncertainty about this direction is whether the United States would agree to a JSF sale to Taiwan. Even if a sale were approved, because of tight early production schedules, it would likely be more than a decade before the aircraft would become available.

The SAM-Dominant Force is an example of a force structure that invests first in SAMs while keeping only as many fighter aircraft as the remaining budget allows. The analysis in Chapter Three showed that the SAM-Dominant Force overinvested in both Patriot and air defense platoon capabilities. By modifying that option to invest in 21 air defense platoons and 12 PAC-3 battalions and appropriate missile inventories for the SAMs, Taiwan could retain a fleet of 85 F-16 retrofit aircraft while retiring the rest of the fighter force. Such a force could provide air-sovereignty protection, as described in the Air Sovereignty vignette, for two to three weeks against current threats while meeting all the demand for air defense platoons and Patriots in the Disarming Strikes and Invasion Air Defense vignettes. For the next decade, this looks like a strong and affordable mixed force. It reflects the reality that a next-generation fighter might not be available for at

least a decade, while making an immediate investment in upgrading the SAM force.

The four force structure options were created before we conducted the analysis summarized in Chapter Three, so it is not a surprise that, with the benefit of that analysis, some adjustments are desirable. Table 4.2 adjusts the JSF Only and SAM Dominant options to

Table 4.2
Analytically Adjusted Force Structure Options

Option	Baseline	Mixed Force	JSF-Only Force	SAM-Dominant Force
Retrofit F-16	144	144	0	85
F-CK/IDF	127	0	0	0
Mirage 2000-5	57	0	0	0
JSF STOVL (F-35B)	0	0	42	0
AIM-120 (additional)	576	2,676	1,768	2,440
PAC-3 (additional)	0	4 launchers, 300 interceptors	0	12 launchers, 900 interceptors
Air defense platoons	0	21	21	21
Invasion Air Defense Vignette: Clear 18 two-hour windows	No	Partial (if <75% radar attrition)	No	Yes
Invasion Air Defense Vignette: Handle PLA surge	No	Partial	No	Yes
Disarming Strike Vignette: Engage 200 attacking aircraft	No	Yes	Partial	Yes
Air Sovereignty Vignette: Days contested (current, developmental)	62, 31	36, 16	98, 25	22, 10
20-year cost difference (billions of BY 2013 US\$; negative numbers indicate savings)	-2.008	-0.882	0.190	-0.425

NOTE: BY = base year. AIM-120s and PAC-3s in this table are in addition to Taiwan's existing inventory.

align them with the preceding comments. These changes prioritize investments in the ground-based air defenses while trying to keep some fighter aircraft in the inventory. The table also uses the analytic benchmarks derived from the vignettes to indicate the capabilities each option might provide in situations like the three vignettes analyzed in this report.

Another possible direction for Taiwan's air defense investment is to choose to completely eliminate its fighter force. The immediate political feasibility of this is probably low, but it should not be rejected reflexively. Historically, there have been inflection points in military technology when one previously potent, or even dominant, military technology was suddenly undone by some adaptation that made it much less effective or, in some cases, completely useless. In many cases, countries have learned the hard way about these developments when they suffered embarrassingly lopsided defeats.

In this case, fighter aircraft are not completely obsolete, but, on Taiwan, the combination of modern, mobile SAMs and precision-strike weapons does place tight constraints on their role in future conflicts to situations involving very limited use of coercive force, and SAMs offer a clearly better option.

Closing Thoughts

Although Taiwan's air defense problem is perhaps the most difficult in the world, we do not see it as hopeless. In this report, we have considered a range of future force structure options. All of them are affordable, but our analysis showed that the way in which Taiwan uses its finite air defense dollars can lead to profoundly different outcomes. To continue to provide a credible deterrent and be seen as having the potential to contest its own airspace, Taiwan needs to substantially reduce the size of its fighter force and invest in SAM capabilities. It then must refine survivable concepts of operations for those forces and train highly competent forces to operate in stressing warfighting environments. The SAM investments are enabling capabilities: They clear the airspace of threats so that other military capabilities can perform critical functions, such as counterattacking landed forces. In this sense, the air defense investments also need to be linked with modernization

steps taken across other defense missions. Although Taiwan faces a very challenging problem, it can still make itself a very hard target. The most important step here might be breaking with the past and rethinking how to control airspace under heavy threat, as well as learning to integrate these new air defenses with new strategies and tactics for Taiwan's overall defense to meet this daunting challenge.

Cost Estimation Methods

To inform more-realistic choices for Taiwan’s future air defense program, we conducted three types of cost estimates. We estimated the overall funding that Taiwan might spend on future air defense modernization, spending to operate current air defense programs, and the cost to acquire and operate potential new platforms. These estimates are not budget-quality estimates but rather should be considered rough-order-of-magnitude estimates to help guide decisions about future investment allocations.¹ Once Taiwan selects one or a small number of potential options, higher-fidelity cost estimates should be initiated.

The cost estimates also rest on several assumptions. We assumed a flat budget for Taiwan’s air defense force. We assumed that Taiwan’s current fleet of fighters will remain constant for the next 20 years and that therefore cuts to the existing size of the fighter force equate to future budget savings. Similarly, we assume a 20-year life cycle in estimating costs of both current and new systems. This is a fairly standard time frame used in conducting cost analysis of military systems. We assumed a 3-percent real discount rate for time value of money, so annual operating costs of current platforms and the life-cycle costs of new platforms reflect that discount rate over the 20-year life cycle.

In this report, costs reported are normalized to fiscal year 2013. Thus all costs represent the purchasing power in 2013. Historical figures are inflated to equate with 2013 purchasing power, and similarly projected future costs are expressed in fiscal year 2013 units. The ratio-

¹ A rough order of magnitude is frequently used as a low-fidelity prediction of final costs to satisfy early financial planning needs.

nale for this is that a policymaker is dealing with current-year budgets, so expressing costs with a common unit allows for intuitive comparison of costs across decades.

To estimate future modernization funding, we took an average of the published modernization figures for the past ten years and assumed that Taiwan would spend a comparable amount on modernization annually in the next 20. Although this is certainly not a prediction, it does provide a benchmark for consideration. It is also a reasonable starting point given that Taiwan's future defense budget is formulated according to a political process that involves both elected and appointed leaders in the executive and legislative branches of Taiwan's government, leaders who will change continuously through this period as elections are held and new officials appointed. An alternative would be to estimate future GDP and make assumptions regarding the share that will be devoted to defense. This alternative suffers from two problems: accurately predicting GDP over a 20-year period and accurately predicting the share of GDP that Taiwan will devote to defense.

From 2004 to 2013, Taiwan spent, on average, NT\$81 billion in then-year funding on military investment, or acquisition. We then adjusted that to current-year dollars. Because we do not have Taiwan inflation adjustment factors, we used the inflation adjustment table published by the U.S. Department of Defense.² When adjusted to current new Taiwan dollars, the average spending on military investment has been NT\$87.5 billion annually. We then needed to estimate the fraction that might be spent on air defense. Historically, about 45 percent of acquisition costs go to major acquisition purchases, which we assume will be the case in Taiwan. Of this, we then needed to estimate how much funding would be devoted to air defense. We assumed 20 percent, assuming that air defense is one of several budget areas within Taiwan's defense budget. This allowed us to derive (NT\$87.5 billion \times 0.45 \times 0.20 = NT\$211.7 billion over 20 years), which is about \$6.7 billion that we assume will be devoted to future acquisition of air defense capabilities. Again, this is probably a conservative estimate, so

² Naval Center for Cost Analysis, "NCCA Inflation Indices and Joint Inflation Calculator," updated January 29, 2015; referenced March 2014.

Taiwan could be planning to spend more. Having calculated the air defense modernization budget, we also calculated how much Taiwan spends in operating costs on its current fighter and Patriot force.

Taiwan devotes a substantial share of its current budget to O&S costs of existing fighter aircraft. Although this is how Taiwan currently chooses to invest in air defense capabilities, that could change over time, and, in Chapter Two, we explicitly consider how divestments of current fighter aircraft might free resources for new investment, given our assumption that Taiwan would not fundamentally increase the share of the defense budget devoted to air defense.

To estimate Taiwan's current spending on air defense, we used cost data we obtained from the Ministry of National Defense that tallied operational expenses incurred in 2007 for several classes of air defense units. We assume that these figures, although they capture only one year, are representative of a typical operational year. The data were grouped by unit, such as the 401st Tactical Fighter Wing, based at Hualian. It indicates the types and number of aircraft in the unit that year. It also provides a cost breakdown among the following categories: personnel costs, operations and maintenance, fuel consumption, equipment maintenance, unit maintenance, and exercise fuel and ammunition. It also includes military investment to maintain the main combat weaponry and facility costs. The costs were in U.S. dollars and used an exchange rate of NT\$31.6 to US\$1. The data provided costs for three fighter units, each operating one of the three types of fighter aircraft in the service. For the F-16s and F-CK aircraft, we assumed that these data were representative of the whole fleet. For the Mirage, the 499th Tactical Fighter Wing includes all 57 aircraft. Starting with these data, we normalized them to BY 2013 amounts and derived per-unit costs of the three types of fighter aircraft and for the Patriot system. The results are shown in Table 2.1 in Chapter Two.

These estimates of current operating costs are important because we used those to pay for modernization costs in the force structure options. All of the options, except for the Baseline force, had some divestment of current fighter aircraft that was used to pay for modernization spending. Thus we counted a divestment of the entire Mirage fleet as freeing US\$4 billion in operating costs that Taiwan would have

to pay if it continued to operate the Mirage fleet for another 20 years. Absent any information regarding the expected life-span of the current fleet, we assumed that each platform could operate for another 20 years. If it plans to retire them earlier, the realized savings would be less. If it intends to operate a platform beyond 20 years, the realized savings of a divestment now would be greater.

The projected costs of new systems were the final element of our cost analysis. We estimated both the acquisition cost of the new system and its future operating costs over a 20-year period to arrive at a life-cycle cost estimate. The primary sources for these cost estimates are SARs, status reports provided to Congress as required in 10 U.S.C. 2432 for all Major Defense Acquisition Programs. SARs provide acquisition costs and operating costs, when available. In cases in which a system has yet to be fielded, we estimated operating costs using comparable systems. Additionally, we considered previous Foreign Military Sales (FMS) transfers of these systems, which are publicly available; however, the unit costs for FMS tend to fluctuate.

To determine the acquisition costs of potential new systems, we used the PAUC. This is the average unit cost considering the costs (or estimated costs) for the whole life of the program. This will be higher than the average procurement unit cost, which does not incorporate research and development costs but is often used in reporting military acquisitions. We used the more inclusive figure because we assumed that, if the U.S. government were to sell a system to Taiwan, the price would recoup some of the research and development investment for that system.

We estimated the operating costs of the system using available SAR data. SARs typically report an annual operating cost estimate. Although the costs reflect historical experience for the U.S. military to operate such systems, Taiwan might have some fundamental differences that would change the annual operating costs of the same or comparable systems. For instance, Taiwan labor costs will be different. Taiwan might also use equipment differently; it might spend different amounts of time in a given year operating a particular system for training and exercises. Although we recognize that there will be absolute differences in costs, using the SARs gives us a reasonable estimate of

future operating costs for this level of analysis.³ Table A.1 reports the acquisition and 20-year life-cycle cost estimates of each new system considered in the report. In Chapter Two, Table 2.3 contains our complete cost estimates for packages of both existing and potential new systems included in the options.

Table A.1
Cost Estimates for the Major Air Defense Systems Considered, in Billions of Base Year 2013 U.S. Dollars

Item	Acquisition Cost (PAUC)	Annual O&S Cost	20-Year Life-Cycle Estimate (per unit)
F-16A/B retrofit	23.74	2.11	80.44
F-16C/D new	141.65	2.2474	202.04
JSF STOVL (F-35B)	156.85	13.3357	515.18
AIM-120	1.82	0.0144	2.21
AIM-9X	0.73	0.0145	1.12
IFPC-2 MML	7.09	0.142	10.89
Sentinel radar AN/MPQ-64F1	8.65	0.992	35.32
IBCS	15.26	0.413	26.35
PAC-3 fire unit (launcher and radar)	274.02	5.187	413.41
PAC-3 missile	4.11	0.071	6.01

SOURCES: SAR data; Army Contracting Command data; National Research Council Committee on an Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives, 2012; and DSCA congressional notifications.

³ In one case, the F-16C/D considered in Appendix D, we used data from a recent FMS transaction to Egypt to estimate O&S costs for that system.

Approaches to Vignette Analysis

A key challenge in conducting the research reported here is the lack of reliable performance data about the systems analyzed. The analysis is based on expert judgment about the relative capabilities of the systems, coupled with sensitivity tests of key variables that might change outcomes. We have converted these judgments into specific measures, which we explain in more detail in this appendix. The absolute values we have assigned are notional, but they convey our judgment about the relative strengths and weaknesses of these systems. The report compensates for some of this uncertainty by showing sensitivity analysis for SEAD and air defense interaction that captures a performance range of Red- and Blue-force interactions and highlights the factors that matter. The report captures the relative strengths and weaknesses of the different systems being considered and highlights the challenge of fighting a numerically superior and technically sophisticated opponent when there are no sanctuary operating locations.

Air Sovereignty Vignette Analytic Method

This section describes the methods, assumptions, and data used to estimate aircraft loss rates in a representative engagement between opposing fighters from Taiwan and China. We scaled up this loss rate according to a specified frequency of engagements per day on a linear basis. We then subtracted daily losses from the number of available fighters for each force structure option. Comparisons between options essentially boiled down to two key attributes: (1) the number of avail-

able fighters at the start of the conflict and (2) the estimated loss rate in a single engagement.

The fluid nature of air combat and its dependence on differences between friendly and adversary weapon systems and tactics, techniques, and procedures is such that predicting who wins a particular engagement and why is not straightforward—air combat is highly dynamic as fighters maneuver to gain positional advantage to maximize lethality and survivability. Assessments based solely on comparing system point performance can overstate the effectiveness of air systems compared with that in actual or even simulated combat.

We chose to use a heuristic approach, based on analytic judgment, to explore the force structure implications of high-level generalizations about the relative strengths of opposing air-to-air systems at the unclassified level. A more thorough analysis using complex computer modeling and simulation about all of the systems and tactics would provide the best comparison; however, this was beyond the scope of our study.

Assumptions

Our analytic results are based on the following key assumptions. Changes to these fundamental assumptions would significantly alter our estimates of expected losses per engagement and attrition over time:

- Combat occurred in the context of a notionally representative 2v4 scenario, with results that are repeatable and scalable over the duration of conflict.
- PLA and ROC Air Force (ROCAF) fighters are supported by ISR assets (GCI and AWACS), so neither side surprises the other or catches it off guard.
- PLA and ROCAF fighters are capable of detecting, tracking, coordinating targets, and employing AAMs at BVR conditions (greater than 20 nm).
- Combat consisted of a single volley of MRAAMs, with no follow-on volleys or reattacks. This is consistent with a low-intensity skirmish type of encounter.

- The effects that electronic attack (EA) can have on system effectiveness are notional and based on EA technology class and fielded (IOC) date.
- Subject-matter expert views informed development of comparative system effectiveness probability data.

These analytic assumptions and associated data were necessary given the unclassified nature of the study and the unavailability of valid effectiveness data from publicly accessible sources. Although it is imperfect, we believe that, on balance, it is a good approach that captures the comparative strengths and weaknesses of the examined fighters.

Fighter loss rates were calculated using Equations B.1 through B.3, with data based on analytic judgment of nominal missile probability of hit (P_{hit}), P_k given a hit (P_k/h), and probability of being decoyed by EA measures by the adversary. These parameters combine to determine overall system P_k for a single firing (also referred to as single-shot P_k). Tables B.1 through B.4 show the data for the examined ROCAF and PLA fighters, respectively, against current and developmental PLA threat systems, with key differences reflected in values for P_{hit} and EA adjustment factors. Note that the EA factor is not the same as probability of being degraded or decoyed but rather the inverse of this (i.e., $1 - degrade$). For example, in the case of F-CK/TC-2, we assumed an EA factor of 0.3 (30 percent) against PLA aircraft RF jammers, which equates to a 70-percent degrade.

$$P_k = P_{hit} \times P_k / h \times EA. \quad (B.1)$$

$$killsperengagement = PLAshots \times P_k. \quad (B.2)$$

$$lossesperday = engagementsperday \times killsperengagement. \quad (B.3)$$

Note from Table B.1 that the overall P_k for a particular ROCAF fighter is dominated by the assumed effectiveness of the opposing PLA fighter's defensive avionic system (EA factor). We assumed that the

Table B.1
System Effectiveness Data: Republic of China Air Force Versus Current People's Liberation Army Fighters

ROCAF Fighter and Missile	P _{hit}	P _{k/h}	EA Factor	P _k
F-CK with TC-2	0.80	0.70	0.30	0.17
F-16A/B with AIM-120 Mirage 2000 with MICA	0.80	0.70	0.50	0.28
Retrofit F-16 and F-16C/D with AIM-120	0.80	0.70	0.60	0.34
JSF STOVL with AIM-120	0.80	0.70	0.70	0.39

SOURCE: Our assumed values based on analytic judgment.

Table B.2
System Effectiveness Data: Current People's Liberation Army

PLA Fighter and Missile	P _{hit}	P _{k/h}	EA Factor	P _k
J-11A FLANKER with AA-10 versus F-CK, Mirage, or F-16A/B	0.60	0.70	0.30	0.13
J-11A FLANKER with AA-10 versus retrofit F-16, or F-16C/D	0.40	0.70	0.20	0.06
J-11A FLANKER with AA-10 versus F-35	0.10	0.70	0.10	0.01
J-10/J-11B modified FLANKER with PL-12 versus F-CK, Mirage, or F-16A/B	0.60	0.70	0.50	0.21
J-10/J-11B modified FLANKER with PL-12 versus retrofit F-16, or F-16C/D	0.40	0.70	0.50	0.14
J-10/J-11B modified FLANKER with PL-12 versus JSF	0.20	0.70	0.25	0.04

SOURCE: Our assumed values based on analytic judgment.

oldest and least capable systems, such as the F-CK, Mirage 2000, and F-16A/B would be significantly more vulnerable to PLA RF countermeasures than newer fighters, such as F-16C/D Block 50 standard and JSF STOVL, are. For example, *each* F-CK/TC-2 firing is expected to kill 0.17 PLA fighters, whereas the JSF STOVL armed with the latest AIM-120 variant is expected to kill 0.39 fighters when fired. Additional firings scale the expected number of kills (e.g., 1.56 out of four PLA fighters killed by JSF STOVLs firing four missiles).

Table B.3**System Effectiveness Data: Republic of China Air Force Versus Developmental People's Liberation Army Fighters (J-11B Upgrade/J-16)**

ROCAF Fighter and Missile	Phit	Pk/h	EA Factor	Pk
F-CK with TC-2	0.60	0.70	0.20	0.08
F-16A/B with AIM-120 Mirage 2000 with MICA	0.60	0.70	0.40	0.17
Retrofit F-16 and F-16C/D with AIM-120	0.60	0.70	0.50	0.21
JSF with AIM-120	0.60	0.70	0.60	0.25

SOURCE: Our assumed values based on analytic judgment.

Table B.4**Effectiveness Data: Developmental People's Liberation Army (J-11B Upgrade/J-16)**

J-11B Upgrade/J-16 Armed with PL-15	Phit	Pk/h	EA Factor	Pk
Versus F-CK, Mirage, or F-16A/B	0.80	0.70	0.60	0.34
Versus retrofit F-16 or F-16C/D	0.60	0.70	0.60	0.25
Versus JSF	0.40	0.70	0.35	0.10

SOURCE: Our assumed values based on analytic judgment.

Table B.2 provides similar data for PLA threat systems and captures the variation expected in platforms between the J-11A FLANKER and the J-10/J-11B FLANKER. It also captures the gradation in effectiveness that each of these systems is assumed to have against the different systems that either Taiwan currently fields or is under consideration in this report. Two missiles are included in Table B.2 because the PLA currently operates both the Russian semi-active AA-10 missile and indigenously produced PL-12 active radar missile, which have different capabilities and limitations. Moreover, we assigned lower values for PLA missile Phit and EA factor given the use of risk-averse, survivability-enhanced tactics flown by ROCAF pilots (see Figure 3.1 in Chapter Three) and presumed lower susceptibility to PLA countermeasures by the more-capable F-16C/D and JSF STOVL fighters equipped with the latest RF countermeasures.

The results shown in Chapter Three are the results of assessments of a representative 2v4 engagement. Because a mix of PLA systems is expected, these calculations average the effectiveness data of the two relevant PLA systems from Table B.2—for instance, an engagement for the JSF-Only Force option would include two JSF STOVLs against four aircraft with the average characteristics of the J-11A FLANKER and the J-10/J-11B.

Tables B.3 and B.4 provide effectiveness data on Taiwan fighter systems against PLA systems under development, the J-16/J-11B upgrade, and data on the system effectiveness of these threat platforms armed with advanced air-to-air weapons. The overall values for P_k are significantly lower for the current PLA threats than for the ROCAF. We believe these differences to be an accurate reflection of the relative capabilities and limitations of these two current fighter systems in our representative 2v4 combat vignette; this near-term P_k advantage for ROCAF is, however, essentially reversed when developmental PLA threats, such as J-16, are considered.

Now that we have quantified system effectiveness (P_k), we can determine the average number of expected losses in a single engagement by combining these data with the expected number of shots taken in our 2v4 engagement. These data for ROCAF and PLA fighters are as follows:

- ROCAF fighter shots per engagement in a 2v4 scenario
 - F-CK: two
 - F-16A/B: two
 - Mirage: two
 - retrofit F-16 or F-16C/D: four
 - F-35: four
- PLA fighter shots per engagement in a 2v4 scenario
 - J-10/J-11/Su-30 versus F-CK, F-16, or Mirage: four
 - J-10/J-11/Su-30 versus F-35: two.

The radar, combat system, and EA factors combine to allow us to estimate how many shots each type of aircraft is likely to be able to fire in an engagement. Tables B.5 and B.6 show our assumptions

about shots per engagement. In order to achieve 80 percent Phit, the less capable ROCAF fighters (F-CK, F-16A/B, and Mirage 2000) are restricted to engaging one opposing PLA fighter at a time (or two out of four) using single-target track (STT) mode; this STT restriction, however, does not apply to the more-capable retrofit F-16, F-16C/D, and F-35 export aircraft. Although this might seem biased, it is consistent with improved track-while-scan fire control radars that presumably would be offered to Taiwan.

Conversely, the numerical superiority allows all four PLA fighters to employ weapons against the two ROCAF using STT with one exception—against the stealthy F-35. We assumed that only two PLA fighters would survive and reach weapon employment range against this stealthy fighter. However, the effectiveness of these two AA-10/PL-12 shots is believed to be very poor, as noted in Table B.2.

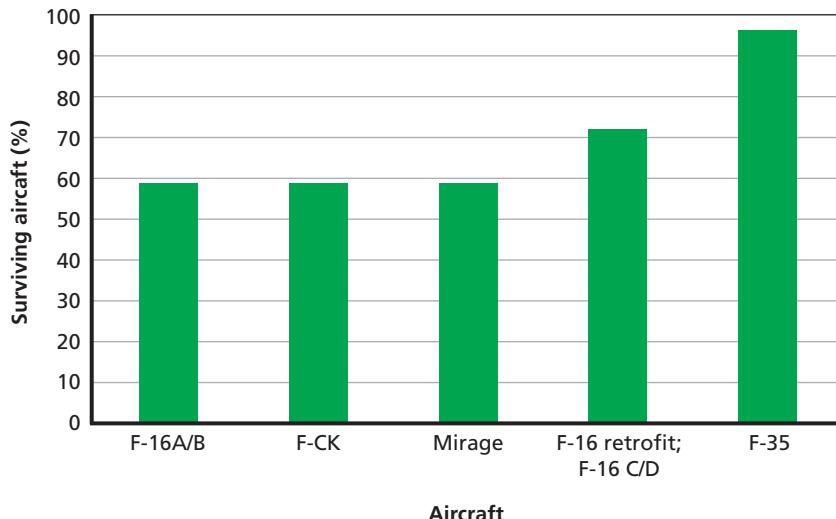
For comparison purposes, the results obtained from Equations B.1 and B.2 can be expressed in terms of ROCAF fighter survivability and exchange ratio, which is defined as the number of PLA fighters killed divided by ROCAF losses. These are plotted in Figures B.1 through B.4.

ROCAF loss rates were essentially the same for the older, least capable fighter; marginally improved with the F-16C/D (and retrofit F-16); and vastly improved with the F-35. Although PLA losses are immaterial to this study, it is sometimes useful to show results expressed in terms of fighter exchange ratio where differences in both lethality and survivability are combined.

Total losses per day are determined using Equation B.3 for a specified number of 2v4 CAP engagements per day associated for three levels of conflict intensity:

- low intensity: one CAP is engaged every day
- medium intensity: three CAPs are engaged every day
- high intensity: seven CAPs are engaged every day.

As the Air Sovereignty vignette suggested, the intensity and number of violent confrontations have a strong effect on how quickly the fighter aircraft are drawn down. The analysis earlier in Chapter

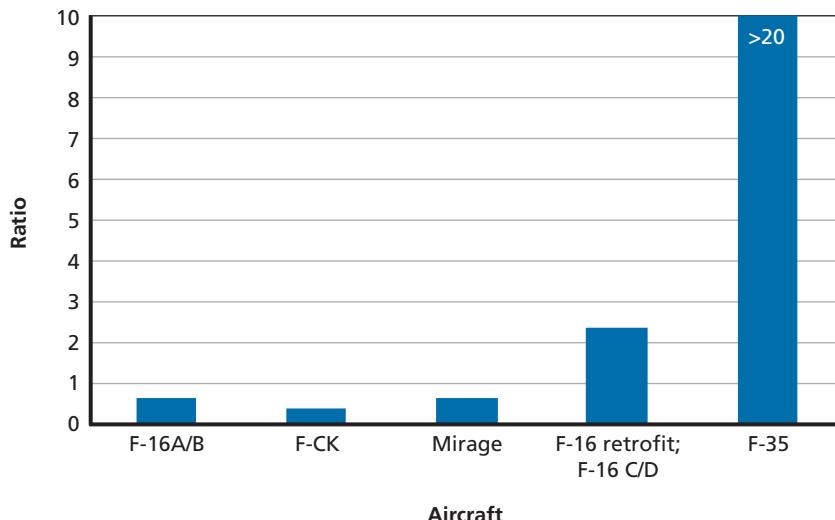
Figure B.1**Republic of China Fighter 2v4 Survivability Against Current People's Liberation Army Threats (J-10/J-11B PL-12)**

RAND RR1051-B.1

Three treated this as a uniform set of engagements over time to capture steady pressure from a conflict. The reality is that any real-world conflict is, in all probability, less regular, with larger engagements and longer periods between engagements more realistic.

When we look at the historical record for this type of conflict, we do not find a great many conflicts on which to fall back for guidance. For instance, the War of Attrition in the Middle East between Israel and its neighbors had periods of low-level conflict, as well as very intense periods of conflict, including substantial air-to-ground, air-to-surface, and surface-to-air missions and commando raids spanning more than two years, from 1967 to 1970.¹ The continuing direct possibility of a ground war breaking out had significant implications in the conflict. It also shaped operations in ways that limit insights that

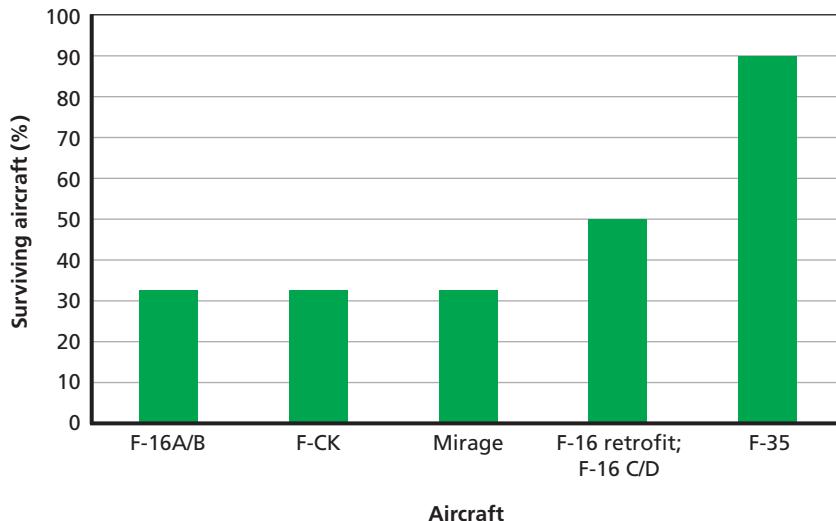
¹ U.S. Operations Provide Comfort, Northern Watch, and Southern Watch over Iraq likewise spanned an extended period of time but had a very different character with much fewer challenges in the air than we are imagining.

Figure B.2**Republic of China Air Force Fighter 2v4 Exchange Ratio Against Current People's Liberation Army Threats (J-10/J-11B PL-12)**

RAND RR1051-B.2

can be drawn from this earlier conflict, except that we can say that it shows a rhythm to battle and a heating up and cooling down of a conflict over a period of two years without a full-scale conflict breaking out between the combatants. Figure B.5 shows a plot of months with significant air activity leading to use of lethal force over the period of the confrontation. Note how the conflict had periods of intense activity and periods with much less activity reported.

Given the lack of a good historical precedent and the highly limited nature of the coercive scenarios in which fighters are relevant, this suggests that Taiwan's force-sizing decision will come down to a question of how many times it wants to challenge PLA fighters but with the recognition that any investment in fighters might take away from capabilities to counter an invasion or a coercive scenario with much larger applications of force.

Figure B.3**Republic of China Air Force Fighter 2v4 Survivability Against the Developmental People's Liberation Army Threat (J-11B PL-15)**

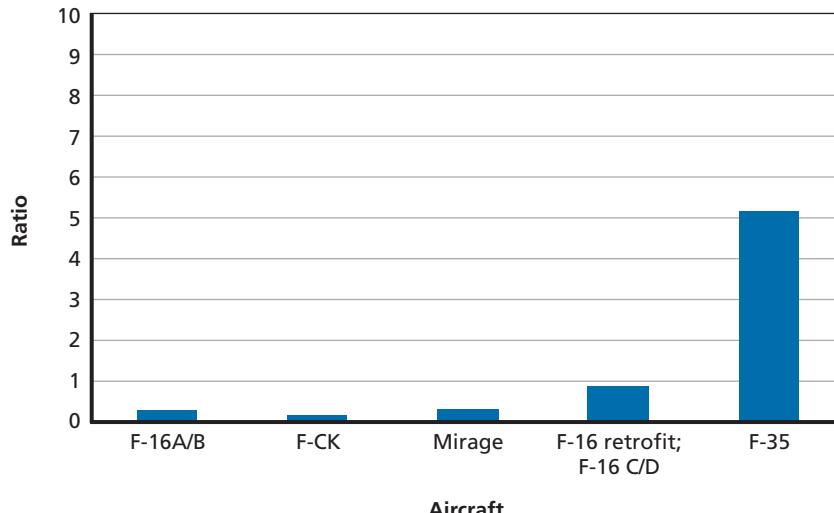
RAND RR1051-B.3

Disarming Strikes Vignette Analytic Method

The exchange analyzed in this vignette is between an air defense platoon firing on a strike package of aircraft and being fired on, in turn, by an escorting SEAD package. We first look at the survival of the Sentinel radar to the SEAD attack using a simple model based on the speeds and effectiveness of the weapons involved. This section describes the self-defense capabilities of the air defense platoon, the capabilities of several SEAD weapons, and how we represented the dynamics of the exchange. Then we discuss the survival of the strike aircraft to the air defense platoon attack, although in less detail because the outcome depends on details of the attack geometry and aircraft performance that cannot be easily predicted or discussed in this report.

Figure B.4

Republic of China Air Force Fighter 2v4 Exchange Ratio Against the Developmental People's Liberation Army Threat (J-11B PL-15)



RAND RR1051-B.4

Figure B.5

Air Activities During the War of Attrition with Significant Uses of Force



Assumptions

The air defense platoon will have an inherent self-defense capability. The initial IFPC-2 Block 1 version is tailored to UAVs and cruise missiles, giving it a self-defense capability against a variety of threat systems that might be employed against it, while the Block 2 version will add the counterrocket and countermortar capabilities to handle smaller and faster threats. Additionally, the threatened radar could turn off immediately after launching missiles and turn over missile guidance to

a second radar. This would have limited effect on engagements because of the limited update requirements of the intercepts and the use of a highly networked engagement system that allows track data from many radars to be used to support engagements. Without this emission beacon, the SEAD weapons would be able to fly to the estimated position of the radar only at the time of launch or from last update from a control aircraft using those aging data.

The accuracy of the weapons flying to coordinates depends greatly on the detection method of the SEAD aircraft and the particulars of the aircraft and SAM geometry and SAM emplacement. If using a single ship direction-finding receiver, the ARM would be following an inaccurate bearing with no range information and would have to be guided on radar emissions nearly all the way to the target. Multi-ship direction finding, in which more than one aircraft shares information, can improve location estimates but can produce an error ellipse on the ground that can still be large compared with the ARM warhead's lethal radius. A TDOA or FDOA technique can give a very fast and accurate geolocation of the emitting radar but depends greatly on having multiple intercept receivers in particular geometries with the radar to obtain the best accuracy of fix; however, this adds complexity to the operation by requiring very good connectivity between two or more aircraft and sophisticated fusion of real-time data. The wide aircraft separation needed for the best results might have one intercept receiver trying to detect the radar side lobes that are blocked by a terrain feature, further reducing accuracy.

Imaging the radar directly could be implemented with a future ARM with a terminal seeker, such as the millimeter-wave seeker planned for the U.S. Advanced Anti-Radiation Guided Missile.² The KD-88 ALCM has an EO camera and is steered from the launching aircraft. The radars and MML vehicles could also be imaged directly using synthetic aperture radar or EO sensors from other ISR aircraft,

² See Austin Miller, *Advanced Anti-Radiation Guided Missile: Strengthening DEAD Capability in the Fleet*, 43rd Annual Armament Systems: Gun and Missile Systems Conference and Exhibition, Alliant Techsystems, April 21–24, 2008.

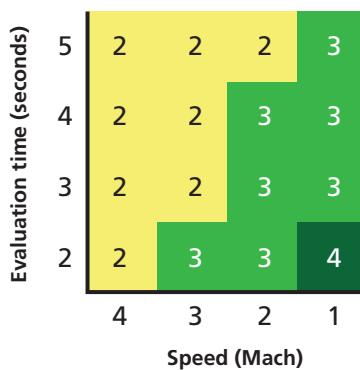
although the air defense platoon would likely already be moving by the time the images could be acted on.

Another factor contributing to radar survival is the speed of the weapon used by the SEAD aircraft. This can range from Mach 4 for the LD-10 ARM, a variant of the PL-12 AAM; to Mach 1.5 for the YJ-91 ARM; to less than Mach 1 for the KD-88 EO-guided missile. This speed, combined with speed of the AIM-9X missile (an average of approximately Mach 2 from launch to impact), determines the time to complete one engagement. That plus the time it takes the air defense system to evaluate the results of the engagement and to pick new targets limits the number of volleys the air defense platoon can take against the SEAD weapons.

Figure B.6 shows the number of volleys that can be made against weapons of different speeds and with different times required for evaluation between volleys.

Although Figure B.6 shows the Mach 4 SEAD weapon allowing two volleys against it, in most cases, it is close to allowing only one volley if the air defense platoon follows the shoot-look-shoot strategy described above. This strategy minimizes interceptor use by having the

Figure B.6
Number of Surface-to-Air
Missile Interceptor Volleys
Given Different Weapon Speeds
and Evaluation Times



SAM evaluate the results of each volley in order to fire only the missiles needed to intercept the surviving weapons. If the maximum engagement range of the AIM-9X were shorter than 10 km because of radar jamming or some other effect, the air defense platoon would have less time to engage. In this case, the platoon could adopt a shoot-shoot strategy, launching a second volley of interceptors based on the predicted number of surviving SEAD weapons without waiting to see the results of the first volley. This would be more wasteful of interceptors but would guarantee that the platoon could launch two completed volleys and greatly increase its chances of survival.

In the typical operating mode, a SAM will fire two interceptor missiles at each attacking weapon. Figure B.7 shows the resulting chance that a SEAD weapon will get through the interceptors given a P_k against the SEAD weapon of 0.7, 0.6, or 0.5 and two, three, or four volleys. Both interceptor P_k and the number of volleys have a large impact on SEAD weapon penetration. Although two interceptor volleys with 0.7 P_k kill more than 99 percent of the SEAD weapons, two volleys at 0.5 P_k allow more than 6 percent to penetrate.

Figure B.7
Probability of Weapon Penetration: Suppression of Enemy Air Defense

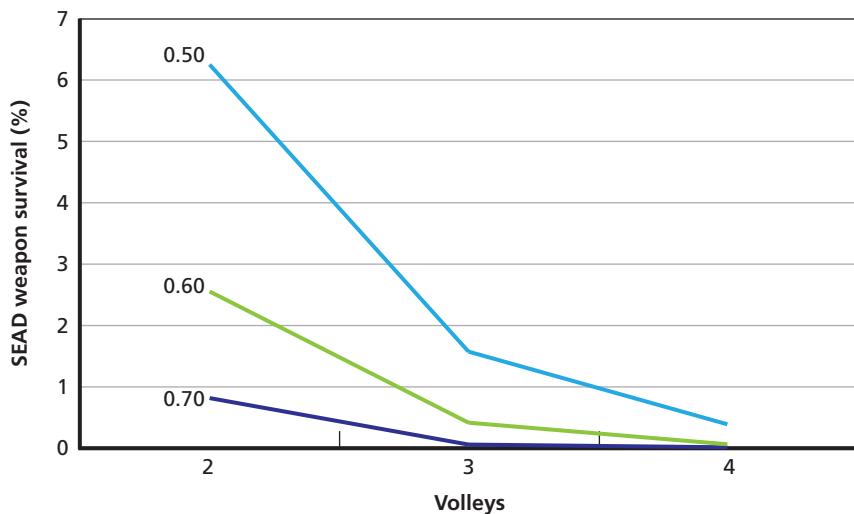


Figure B.7 also shows that slower SEAD weapons, against which the air defense platoon can take three volleys of interceptors, have almost no chance of penetrating. The AIM-9X interceptors have to perform very poorly (0.5 Pk) for the penetration chance to rise above 1 percent. However, we would expect the interceptors to do better against slower SEAD weapons. A penetration chance of much less than 1 percent is essentially no chance, especially after the additional geolocation degradation is applied. At these low percentages, only random events, such as when the radar or interceptors failed or were not operated properly, would determine losses.

Another method attackers can use is to launch more simultaneously arriving SEAD weapons than the radar can track and engage. However, the air defense platoon is designed to service eight to 12 targets in three seconds,³ which is almost certainly more than a plausible SEAD package could coordinate.

Radar survivability is a key factor in the feasibility of using SAMs to defend contested airspace, and there are several factors to consider. First, the slower weapons have great difficulty surviving multiple rounds of interceptors. The KD-88, although having a high potential Pk as an EO-guided weapon, at Mach 0.8 could easily see three or four volleys of interceptors and simply cannot survive.⁴ The YJ-91, although a faster weapon at Mach 1.5, would still see three volleys of interceptors and does not have a good warhead for attacking radars. Even with a poor interceptor performance (0.5 Pk), less than 2 percent of the weapons would survive and would then likely have less than a 10-percent Pk against the radar. The LD-10 has the best chance, with its high speed and a warhead optimized against radars. With two interceptor volleys

³ Cruise Missile Defense Systems Projects Office, “Indirect Fire Protection Capability Increment 2: Intercept, Multi-Mission Launcher Final Concept Overview,” briefing slides, January 25, 2013.

⁴ In other situations, large numbers of slow weapons can overwhelm the simultaneous engagement capability of the SAM or run it out of missiles. The air defense platoons are much less vulnerable to this tactic, with their AESA radar, fire-and-forget missiles, and large ready inventory.

and a P_k of 0.5 to 0.65 for the warhead, the chance of killing the radar rises as high as 3 percent.⁵

The error in geolocation of the radar is another factor in radar survival. The accuracy of TDOA and FDOA systems is dependent on the geometry between the two receiving aircraft and the emitting radar. For the best TDOA accuracy, the receiving aircraft must be on significantly different bearings from those of the target; for best FDOA accuracy, aircraft must have different velocities from that of the target. A representative sampling of different geometries has almost 75 percent yielding ellipse areas in which the radar might be located within a 2,500-m² ellipse, with 25 percent in a 25-m² ellipse. Table B.7 shows the distribution of ellipse areas.⁶

A SEAD weapon with an ARM seeker will not be able to take advantage of its passive homing capability because the Sentinel radar will complete its engagement well before the weapon reaches it. In the future, placing an imaging seeker on the ARM would allow it to compensate for larger geolocation errors while making it less vulnerable to deception measures. A missile, such as the KD-88, with an EO camera

Table B.7
Distribution of Location Ellipse Areas
from Time and Frequency Difference
of Arrival

Ellipse Area (m ²)	Percentage of Cases
25	25
100	20
2,500	30
10,000	10
250,000	10
1,000,000	5

⁵ The actual number of LD-10 missiles (or similar high-speed SEAD weapons) in China's inventory would be a number for Taiwan's force planners to watch closely.

⁶ Kimberly N. Hale, *Expanding the Use of Time/Frequency Difference of Arrival Geolocation in the Department of Defense*, Santa Monica, Calif.: RAND Corporation, RGSD-308, 2012.

that is steered from the launching aircraft, can also overcome geolocation errors but is a slower missile that is more vulnerable to defenses.

The final factor in radar survivability is the lethality of the SEAD weapon against the Sentinel radar, which varies with the size and type of warhead. The LD-10 is based on an AAM and is designed to kill its targets by throwing a cone of fragments ahead of it. Its target must fall within the fragment pattern and be struck with enough fragments to do lethal damage. The U.S. AGM-88C High-Speed ARM has a 66-kg warhead with more than 12,000 fragments that are projected in a cone.⁷ If we assume the same warhead design, the LD-10 with a 24-kg warhead would have approximately 4,400 fragments. If we assume that the Sentinel would need to be struck by ten fragments over 1 m² of surface, the LD-10 would have a 12-m lethal radius. If only five fragments were needed, the lethal radius would be 17 m. Beyond the lethal radius of the weapon, the probability of killing the radar falls off as the square of the distance. At double the lethal radius, the P_k against the radar would be 25 percent. However, because relatively light fragments do the damage, this weapon is most effected by possible physical protection of the radar. The Sentinel is a small radar, and something as simple as a Kevlar blanket thrown over it might provide substantial protection from this type of small fragmentation weapon.

Another threat to the radars comes from the YJ-91, an air-to-ground missile with an 87-kg general-purpose warhead that is designed to destroy both hard and soft targets with blast effects and fragments. Blast effects fall off as the cube of distance and require small CEPs against equipment in the open. The lethal radius of the YJ-91 is roughly 2 m against medium-hardness targets.⁸ The warhead fragments are larger and can carry long distances, but there are fewer, and their dispersal pattern would not be optimized against a radar.

The KD-88 missile is an air-to-ground missile with a 165-kg warhead and can be steered into the radar via a command link from the

⁷ "AGM-88 HARM (High-Speed Anti-Radiation Missile)," *Jane's Air-Launched Weapons*, April 29, 2013.

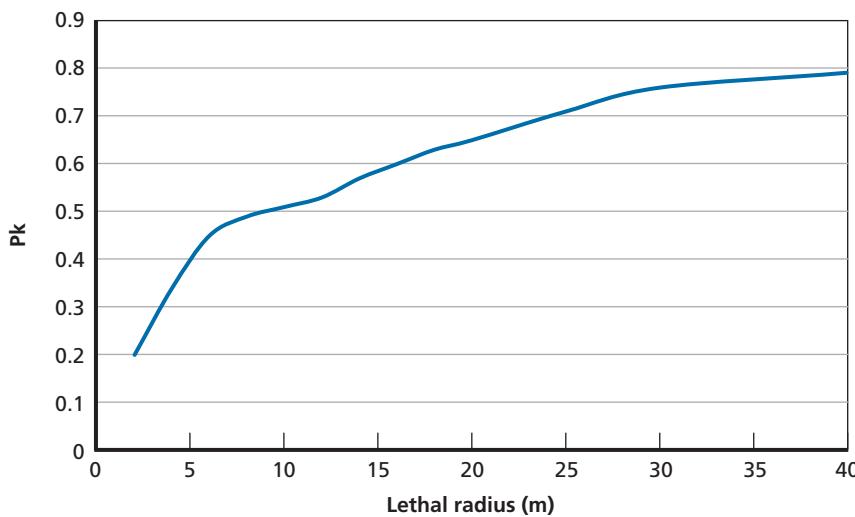
⁸ Ted Harshberger, *Long-Range Conventional Missiles: Issues for Near-Term Development*, Santa Monica, Calif.: RAND Corporation, N-3328-RGSD, 1991.

launching aircraft. However, it is vulnerable to camouflage that can hide the radar, such as multispectral netting and smoke.

Figure B.8 shows the P_k against the Sentinel radar for a range of lethal radii, assuming the distribution of geolocation error ellipses described in the appendix.⁹ The plausible lethal radius of the LD-10 lies between 10 and 20 m, with P_k s between 0.50 and 0.65. The lethal radius of the YJ-91 is likely less than this, while the P_k of the KD-88 is potentially high if the SEAD aircraft can visually acquire the radar.

The tempo of the air war in the Disarming Strikes vignette is assumed to be lower than during the full invasion. Over extended periods, sortie rates are much lower than surge rates. Even with 600 fighters within range, China might fly only 300 sorties in a day, or six four-ships in a two-hour window. These might be divided in equal proportions to air-superiority, ground-attack, and SEAD roles. Thus a single strike could be composed of 12 fighters, four in each role. In the

Figure B.8
Probability of Kill for Weapon with Lethal Radius Based on Time- and Frequency-Difference-of-Arrival Geolocation



RAND RR1051-B.8

⁹ These P_k s were generated by running a Monte Carlo simulation.

SEAD role, two fighters could be primarily jamming, and two could carry YJ-91 ARM weapons or guided standoff weapons, such as the KD-88 missile.

Table B.8 rolls all of these factors together to give a range of calculated Pks for a SEAD package carrying four weapons of different types.

In the worst case for the defender, four high-speed LD-10s have a 16-percent chance of killing a Sentinel radar, but this drops to 2 percent or less if the AIM-9X has a better Pk. The YJ-91, because it is slower with a nonoptimized warhead, is significantly less a threat, ranging from 4 percent to less than 0.1 percent Pk. The KD-88, despite having the best Pk against the radar, is so slow that it has a 1-percent Pk at best because the slower speed allows for up to four AIM-9X intercept attempts.

Turning now to the attack by the air defense platoon on the striking aircraft, we start by characterizing the typical engagement situation. The PRC, having destroyed or forced into hiding Taiwan's long-range SAMs and fighters, is carrying out a strategic bombing campaign designed to coerce Taiwan into capitulation. The PRC's preferred method is to use the weapons it has most in supply; direct-attack bombs that must be delivered from short range. Taiwan is trying to deny this attack by placing air defense platoons near these targets to engage the striking aircraft at close range. By making these attacks too

Table B.8
Probabilities of Kill for a Suppression-of-Enemy-Air-Defense Package
Against a Sentinel Radar

SEAD Weapon	AIM-9X Intercepts	AIM-9X Pk	SEAD Weapons Arriving	SEAD Weapons' Pk	Pk Against Sentinel
Four LD-10s	2	0.5 (low)	0.250	0.50–0.65	0.125–0.163
	2	0.7 (high)	0.032	0.50–0.65	0.016–0.021
Four YJ-91s	3	0.5 (low)	0.016	0.8	0.013
	3	0.7 (high)	0.0003	0.8	0.0002
Four KD-88s	4	0.5 (low)	0.016	0.8	0.013
	4	0.7 (high)	0.0003	0.8	0.0002

dangerous, Taiwan forces the PRC to use its more-expensive and less numerous standoff weapons, weapons that can also be intercepted by the air defense platoons.

The air defense platoon near the target would remain in hiding until cued by another system or the attack on the target itself. Because the air defense platoons across Taiwan are netted together through the IBCS, a rotating set of Sentinel radars could turn on briefly one at a time and then turn off and move before there was much possibility of being attacked. With a 75-km air surveillance range,¹⁰ three or four Sentinels could cover most of Taiwan's critical airspace, and a set of six radars could each turn on for ten minutes every hour so that some part of Taiwan was always covered.

We assume that the typical engagement would have the Sentinel radar cued to the presence of fighters within range of its missiles. The air defense platoon would turn on its radar and fire on the aircraft as quickly as is possible. Because we do not know what the particular geometries of the engagements would be or how the AIM-120 missile would perform when fired from the ground, we simply assume the same performance as was posited for the air-to-air engagements in the Air Sovereignty vignette. Because the Sentinel is a modern AESA radar, we use the F-35 parameters, meaning an overall 0.39 Pk per AIM-120 fired. If we assume that two AIM-120s are fired at each aircraft, each aircraft has a 63-percent chance of being killed; if four aircraft are targeted, the expected outcome is 2.5 aircraft killed. There are factors likely to reduce this outcome. The AIM-120 is likely to be less effective when fired from the ground than when fired from high altitude from a moving aircraft. The strike package might have fewer than four aircraft, or some might not be in position to be attacked. The PRC might have more EA support than in engagements at some distance from its coastline. Considering these mitigating factors, a range of one to two aircraft killed per engagement is plausible, with an average of three AIM-120s fired per kill.

¹⁰ ThalesRaytheonSystems, undated.

Invasion Air Defense Vignette Analytic Method

The Invasion Air Defense vignette draws insights from the previous vignette; however, a key difference is that, in the Disarming Strikes vignette, Taiwan can pick advantageous engagements, which leads to favorable exchange ratios. In the Invasion Air Defense vignette, Taiwan has less control over when an engagement will happen. The other main difference between these two vignettes is that the Patriot/TK III SAMs are not used in the Disarming Strikes vignette so that they can be conserved for use in the Invasion Air Defense vignette. The analysis for this vignette adds the outcomes of a series of engagements between Taiwan's SAMs firing interceptor missiles at PLA aircraft and the PLA attacking SAM radars with a combination of aircraft firing SEAD weapons, SRBMs, and MRLs. In the case of the SRBMs and MRLs against the Patriot/TK III SAMs, we assume a simple parametric Pk. In the case of the air defense platoons, we refer to the calculations made for the Disarming Strikes vignette. This section describes the capabilities and vulnerabilities of Taiwan's SAMs.

Assumptions

In the Baseline force structure, Taiwan has 200 PAC-2 and 444 PAC-3 missiles for its nine Patriot batteries.¹¹ The PAC-2 is a long-range anti-aircraft missile with a range of 160 km and a maximum speed of 1,700 m per second.¹² The PAC-3 has increased capability against ballistic missiles but is still capable against aircraft. A Patriot launcher carries either four PAC-2 or 12 PAC-3 missiles.¹³ We assume that each Patriot battery has four PAC-2 launchers and two PAC-3 launchers, for a total of 40 ready missiles. When it runs out of PAC-2 missiles, the battery will reload all launchers with PAC-3s, for a total of 72 ready missiles. The missile for the TK III is similar to the PAC-2, so a battery with six launchers would have 24 ready missiles.

¹¹ "Taiwan," 2012; Kan, 2014.

¹² "MIM-104 Patriot," 2014.

¹³ We assume that the PAC-3 missiles have been upgraded to the MSE variant.

The Patriot radar can guide nine missiles in the final moments of the engagement.¹⁴ Like the AIM-120, the PAC-2 and PAC-3 missiles have active radar that turns on for the last few seconds of flight to guide the missile to its target. If shooting at aircraft that are 100 km away, the missiles will take about one minute to fly out. If shooting two missiles at each target, the battery could take as much as five minutes to shoot all its missiles. In our characterization of the air war, there are 75 airborne targets over the Strait every two hours and 75 over Taiwan. In order to clear the airspace, the Patriots/TK IIIIs need to engage the long-range targets over the Strait while the air defense platoons engage the targets overhead. Having identified 75 targets to engage, we assume that, when 50 are fired on, the remainder will abort, which creates a demand for 100 missiles fired every two hours if two missiles are fired at each target.

The Patriot/TK III radars are threatened by ballistic missile and long-range MRL attacks, as well as SEAD weapons launched from aircraft. If the Patriot/TK III radar requires 60 minutes to tear down and move, the PRC might be able to get targeting information back to a missile battery and launch in time to hit the radar. Although other Patriot/TK III batteries in the area could attempt to intercept the ballistic missiles fired at the engaging radars, this would expose them to attack and ultimately lead to more radars lost. As importantly, none of the force structure options has enough PAC-3/TK III missiles to engage both aircraft and ballistic missiles. If engaged by SEAD aircraft, air defense platoons in the area (in the force structure options that have them) can defend against aircraft-launched SEAD weapons.

The Patriot AN/MPQ-65 radar is a phased-array radar mounted on a two-axle semi trailer with a 5-ton truck as a tractor.¹⁵ The radar is mounted on a flat surface that is mechanically raised from a horizontal position to a near-vertical one. Four screw jacks are used to level the trailer, and power is provided from a separate generator tractor-trailer. The nominal tear-down time for the radar is 60 minutes, which might allow the PRC to get targeting information back to a missile battery

¹⁴ “MIM-104 Patriot,” 2014.

¹⁵ “AN/MPQ-53/-65 Guidance Radar,” 2014.

to launch in time to hit the radar. As discussed with the Disarming Strikes vignette, airborne TDOA systems can generate the location of an emitting radar very quickly. Although we cannot discuss any details in this report, this is essentially the same targeting problem that the PLA has to solve in order to target ships with ballistic missiles, and elements of that decisionmaking process could also be used here. On the other hand, the 60-minute time to tear down and move the radar could likely be decreased, perhaps at some risk of damage. The expected error in a TDOA location of the radar is largely matched to plausible sizes for the ballistic missile cluster warhead footprint, so the chance of the Patriot radar surviving is essentially reduced to the chance that it can move in time. Because this is a large area of uncertainty, we investigate 50-percent and 75-percent probabilities that the radar is destroyed.

Another threat to the Patriot/TK III radar comes from the SEAD aircraft in the air when the SAMs engage. For those force structure options that have air defense platoons, we assume that a platoon is near enough to each Patriot/TK III radar to intercept SEAD weapons. Although this would increase the radar's loss rate by the assumed 5- to 10-percent loss rate from the Disarming Strikes vignette, the loss rate for the radar assumed above is simply designed to provide medium and high categories, and no real insight would come from adding in another small percentage. However, in the force structure options that do not have air defense platoons, the Patriot/TK III radars would have no real defense against the SEAD weapons. Taiwan has a small number of other short-range air defense missiles and guns, but there is no reason to believe that these would be effective against high-speed SEAD weapons, such as the LD-10. Four LD-10s fired on a TDOA or FDOA cue would have better than a 90-percent chance of killing the radar; therefore, in these force structure options, we assume only a 90-percent radar loss rate.

A third category of threat to the Patriot/TK III radars comes from the artillery and MRLs of the landed PRC forces. China currently fields 155-mm extended-range artillery projectiles with a range

of 39 km,¹⁶ which puts at risk any radar deployed on Taiwan's western plains from artillery on the beach. China's 122-mm MRL also has a range of 40 km and a CEP less than 100 m firing unguided rockets.¹⁷ China is also using tactical UAVs to provide real-time targeting to its artillery units. Again, this threat is incorporated in the assumed 50- and 75-percent loss rates.

The air defense platoons also have 75 targets in their assigned airspace, of which 50 must be engaged. An air defense platoon has 20 ready AIM-120 missiles; therefore, at least five platoons are needed to engage 50 targets every two hours. Unlike in the Disarming Strikes vignette, in which the platoon engaged only a few aircraft under favorable circumstances and then immediately escaped, the platoon's purpose here is to engage all the targets it can see and to keep firing until the airspace is clear, while defending itself and nearby Patriot/TK IIIs from SEAD attack.

In addition to numbers of missiles, the platoons are required to clear airspace over a sufficient area. Here, if we assume that each platoon covers airspace out to half the kinematic range of the AIM-120, 12 platoons could cover two 120-by-80-km areas, sufficient to cover both the north and south of Taiwan. The amphibious landings and therefore the counterattack would take place either in the north or south of Taiwan and would be engaged only by the air defense platoons in place. However, once the war begins, the platoons are likely to have difficulty moving large distances, so enough platoons would need to be purchased to cover both areas to be prepared for the initial landings. We assume that equipment can be moved over several days to make up for radar losses and interceptor expenditures.

Sentinel radar survival depends on the number of SEAD weapons fired at it. We estimated 25 SEAD aircraft in the air, which could be divided into six SEAD packages of four aircraft, with each package attacking a single radar site. We also assume that, because long-range

¹⁶ Christopher F. Foss, "Red Heat: China Advances Conventional Tube Artillery," *International Defence Review*, December 2, 2013.

¹⁷ Doug Richardson, "NORINCO Offers MLRS Armed with Guided Rockets," *Jane's Missiles and Rockets*, June 23, 2010.

SAMs are engaging the SEAD aircraft, each package will launch only four SEAD weapons. This is the same average engagement assumed in the Disarming Strikes vignette, which resulted in radar loss rates per engagement of 5 to 10 percent, or 0.3 to 0.6 radars killed per engagement.

Putting all this information together, Table B.9 shows an example of our SAM engagement methodology for the Mixed Force option with four additional Patriot batteries and 300 PAC-3 missiles. The goal for the Patriot/TK III batteries is to engage 50 targets at long range while the air defense platoons engage targets at close range and provide defense for themselves and the Patriot/TK III batteries. The table shows, for each of the 12 two-hour windows, how many SAM batteries and missiles remain, how many ready missiles are on each battery, and how many batteries engage and are killed as a result. The Patriot batteries begin with 16 PAC-2 and 24 PAC-3 missiles, and the TK III batteries always carry 24 missiles, so a combination of two Patriot and one TK III batteries will deliver 104 missiles. Because the attrition rate to the SAM radars is a constant 50 percent in this case, one Patriot and half of a TK III radar are killed. This pattern continues until window 7, in which the PAC-2 missiles have nearly all been expended and the Patriot batteries switch to carrying 72 PAC-3 missiles, requiring only one Patriot battery to engage to meet the goal of 100 total missiles delivered. By the end of the 12 windows, there are four Patriot batteries with only a few missiles, and six TK III batteries with well over 500 missiles remaining. Although more TK III batteries and fewer Patriot batteries could have engaged, because three TK III batteries are needed to replace one Patriot battery with PAC-3 missiles, many more total SAM radars would have been lost if the TK III batteries replaced the Patriots.

The 57 F-35s in the JSF-Only Force structure option lead to a change in tactics for both sides. The F-35's STOVL capability makes it nearly impossible to prevent sorties by attacking runways, so the PRC, in this option, would not expend these ballistic missiles. On the other hand, 57 F-35 aircraft would not be able to prevent the PRC from gaining air superiority over Taiwan by themselves. The design performance parameter for the STOVL F-35 sortie rate is six sorties per day under

Table B.9**Patriot/TK III Engagements for 12 Two-Hour Windows with the Mixed Force, 50 Percent Radar Attrition**

Window	Patriot						TK III				
	Patriot Batteries	Total PAC-2s	Total PAC-3s	Ready Missiles	Patriots Firing	Patriots Killed	TK III Batteries	Total Missiles	Ready Missiles	TK IIIis Firing	TK IIIis Killed
1	13	200	744	40	2	1	12	859	24	1	0.5
2	12	168	696	40	2	1	11.5	835	24	1	0.5
3	11	136	648	40	2	1	11	811	24	1	0.5
4	10	104	600	40	2	1	10.5	787	24	1	0.5
5	9	72	552	40	2	1	10	763	24	1	0.5
6	8	40	504	40	2	1	9.5	739	24	1	0.5
7	7	8	456	72	1	0.5	9	715	24	1	0.5
8	6.5	8	384	72	1	0.5	8.5	691	24	1	0.5
9	6	8	312	72	1	0.5	8	667	24	1	0.5
10	5.5	8	240	72	1	0.5	7.5	643	24	1	0.5
11	5	8	168	72	1	0.5	7	619	24	1	0.5
12	4.5	8	96	72	1	0.5	6.5	595	24	1	0.5
End	4	8	24				6	571			

surge conditions at the start of a war,¹⁸ which would allow half the F-35s to be in the air to meet the PRC's first attacks. Assuming that each F-35 carried and expended six AIM-120s with the 0.39 Pk from the Air Sovereignty vignette, the 25 F-35s would kill nearly 60 PRC aircraft. However, the remaining PRC aircraft would be able to establish CAPs over Taiwan in an advantageous position over further F-35s taking off from the ground. The F-35s in the air would also be at a disadvantage because they would have to land having exhausted their air-to-air weapons with PRC fighters in the same airspace. Therefore, the better tactic for this force structure is to disperse and hide the F-35s on the ground and wait to fly sorties in cooperation with Taiwan's SAMs to open the windows of cleared airspace. Used in this way, the F-35s play the same role as the SAMs and can be compared to them in the number of aircraft that they kill and in how long they can survive.

Here again, there is considerable uncertainty in how the F-35 could operate. In the best of worlds, the aircraft could stay hidden on the ground until the time came to open an airspace window. There are no air defense platoons in this force structure option, so the Patriot/TK IIIIs would engage the PRC fighters over Taiwan in order to allow the F-35s to take off. Then the F-35s would engage aircraft over the Strait, coordinating with the SAMs to avoid friendly-fire incidents. The F-35s would land and rearm at changing locations and launch again to meet the next wave of PRC aircraft in two hours. Although rearming and refueling on the ground for a quick turnaround, the F-35 would be vulnerable to the same ballistic missile attacks aimed at the Patriot/TK III radars. If the airspace over Taiwan could be cleared of UAVs and the PRC's ISR aircraft pushed back far enough, the F-35's radar stealth might allow it to land unobserved. The aircraft, however, would have to operate well clear of the PRC's landed forces, which would be equipped with their own air surveillance radars and SAMs, as well as artillery and MRLs with 40-km range. Landing sites would have to be developed that were out of the clear sight of the PRC's ISR assets, and aircraft camouflaged while on the ground.

¹⁸ Defense Acquisition Management Information Retrieval, *Joint Strike Fighter*, Selected Acquisition Report, RCS: DD-A&T(Q&A)823-198, December 31, 2010, p. 11.

During the few two-hour engagement windows, three Patriot/TK III batteries can engage the 50 targets to clear the near airspace, and the 25 F-35 sorties can clear the airspace over the Strait. However, because there are no air defense platoons to protect the Patriot/TK III radars from aircraft-launched SEAD weapons, the long-range SAMs that engage would suffer a high attrition rate (assume 90 percent) and be largely destroyed after seven two-hour engagement cycles. If we assume that every F-35 sortie flown has a 10-percent chance of being killed on the ground while protected by the Patriot/TK IIIIs, the 57 F-35s are drawn down to 45. Once the Patriot/TK III radars are eliminated, the risk to F-35s on the ground is much greater because PRC aircraft and UAVs will be able to overwhelm the F-35 sorties and follow them to their landing spots and call in coordinates for a ballistic missile, artillery strike, or subsequent aircraft or UAV strike. In this case, losses on the ground could be 50 percent or more for each sortie. Also, F-35s taking off with PRC fighters overhead would be at a disadvantage in the air and would likely suffer a reduced exchange rate. Conversely, as F-35s are killed, additional Patriot/TK III batteries would need to engage the long-range targets that the F-35s could not engage, which would increase the rate of Patriot/TK III radar attrition.

Other Air Defense Systems Considered

We considered but have excluded consideration of several systems, and this appendix explains the rationale for these choices. These include UAVs, land-attack and ballistic missiles, a man-portable air defense system (MANPADS), and vertical takeoff and landing (VTOL) aircraft. In several cases, we do not mean to imply that these platforms have no role in Taiwan's defense force. Mostly, we excluded these systems because other options appear to hold stronger operational potential. Another consideration that influenced these choices was the direct relevance to the air defense mission. In several cases, these capabilities have relevance for Taiwan to play other defense roles, but we do not see a strong air defense role for these systems that would lead Taiwan to invest in and maintain them primarily for that mission. Last is the feasibility of Taiwan acquiring the system, although, as can be inferred from our inclusion of JSFs, that factor was less concerned with political constraints than with more-practical constraints, such as the lack of an open production line.

Unmanned Aerial Vehicles and Unmanned Combat Aerial Vehicles

Although UAVs or unmanned combat aerial vehicles (UCAVs) could also play a role in cruise missile defenses, the primary mission of an unmanned air system at this point in time would be to monitor—or, in the case of UCAVs, strike—surface threats. Therefore, we do not include them for consideration as part of Taiwan's airpower portfolio.

The emergence of UAVs and UCAVs as viable air platforms suggests that they warrant some consideration as alternatives to manned aircraft in the ROCAF. Currently, the ROCAF air assets are tasked with air-superiority, air-to-surface, transport, and ISR missions to directly engage or support combat operations. There are both advantages and disadvantages of manned and unmanned aircraft in each of these roles. A detailed analysis of the advantages of manned versus unmanned aircraft is out of scope for this study; however, the operational environment of Taiwan postulated for each of the vignettes greatly simplifies the problem by posing extremely severe challenges that allow us to use the analysis involving manned aircraft for all larger and more-capable UAVs. This is the case simply because, as UAV size grows to meet the current set of operational requirements (e.g., avionics, payload, propulsion), a UAV or UCAV ends up sharing many of the same characteristics as manned aircraft would, leading to similar survivability and cost profiles of the systems. Savings might be possible using UAVs, but significant changes in the operational requirements of the systems would need to be investigated and integrated into a much larger array of systems to determine whether they were worth the operational trade-offs inherent in the near-term UAV systems. Indeed, the U.S. military is grappling with these issues but, to date, has employed UAVs only for ISR missions and UCAVs for very specific attacks on terrorists in a rather benign threat environment for the UCAV.

It should be noted that UAVs and MANPADS do have a role in Taiwan's overall defense posture, but neither of these types of systems can readily address Taiwan's main requirements in terms of either establishing control of airspace or carrying out the variety of missions at this point in time.

Ballistic or Land-Attack Cruise Missiles

Although ballistic and land-attack cruise missiles could be used strike adversary air bases, and thus contribute to an improved air defense capability, in practice, there are many bilateral constraints on such weapons and some operational limitations. The United States does not field con-

ventional ballistic missiles or ground-launched land-attack cruise missiles of the types that would be relevant for Taiwan. The Intermediate-Range Nuclear Forces Treaty constrains the United States from testing such weapons.¹ Beyond the treaty constraints, the U.S. military has favored other systems—in particular, manned aircraft—to conduct the strike missions that these ballistic or cruise missiles might perform. Manned platforms have advantages in that they hold out the possibility for repeated strikes, while ballistic and cruise missiles are one-time weapons. Without any U.S. sourcing options, Taiwan has developed and fielded its own land-attack cruise missile.

Because we have described how vulnerable Taiwan's air bases are to ballistic and cruise missile attack, it is only natural that we consider using a similar strategy against PLA air bases. Unfortunately, the PLA has a lot of advantages over Taiwan. PLA air bases in the area across from Taiwan tend to be well hardened and numerous. More than two dozen suitable military bases are within fighter range of Taiwan. Taiwan has not made the same investments that the PLA has in strike and reconnaissance capabilities to carry out major attacks on these bases. Nor has it made the investments in sophisticated and layered air defenses to protect these bases. Putting all these factors together drives up the number of missiles Taiwan would need to employ to achieve operational effects. We estimate that Taiwan would need about 22 cruise missiles to cut the runways of a defended air base; shutting down two dozen airfields would take more than 500 missiles. Runway cuts can obviously be repaired, and these would only constrain the aircraft at these bases. Other aircraft based farther inland could surge forward and use civilian airfields. Shutting down a couple dozen PLA air bases over a period of five days would take several thousand weapons. Doing this efficiently would require some bomb-damage assessment capability so that airfields near completion of repairs could be reattacked, but Taiwan would have great difficulty in operating traditional ISR platforms in the heavily defended area across the Strait.

¹ United States and Union of Soviet Socialist Republics, *Treaty Between the United States and the Union of Soviet Socialist Republics on the Elimination of Their Intermediate-Range and Shorter-Range Missiles*, Washington, D.C., December 8, 1987.

A strike component to Taiwan's air defense concept certainly has some relevancy. If nothing else, it might be a cost-imposing strategy that forces the PLA to make hardening investments; however, it cannot be the only element of Taiwan's air defense concept. In developing the force structure options for this report, because we have no information about the number or accuracy of the Taiwan ballistic and land-attack cruise missile systems, we treated them as exogenous factors. Our options do not take resources from these programs.

Man-Portable Air Defense Systems

MANPADs are small SAMs, such as the U.S. Stinger or Russian SA-18. Modern, small, IR-guided SAMs have advanced seekers capable of both resisting countermeasures and engaging aircraft from all aspects; some newer variants now add ultraviolet seekers.² These are formidable systems in their operational envelope once launched at their target. They do not replace SHORAD systems considered in this report, which are tied to launchers and sensors and offer different operational benefits.³

MANPADs provide a distinct value within a limited domain. They have been highly effective in modifying the behavior of attacking forces by increasing risks to aircraft at low altitude. They offer minimal prelaunch signature because of their use of passive sensors, and this provides the element of surprise. Their portability adds unpredictability to their employment. They are quite lethal when launched within their target envelope. Still, they have some employment limitations,

² There are command-guided line-of-sight systems, such as the Thales Starstreak, that command-guide missiles into the target. They are not fire-and-forget systems, and they are relatively uncommon because they require that the operator have more training and stay exposed while directing the missile to the target.

³ The M6 Linebacker systems, which use the Stinger missile, combined with a modified Bradley armored vehicle for mobility and protection, are midpoint between MANPADs and SHORAD systems designed for mass engagements. The M6 allows good support for units on the move but is not a substitute for systems better suited for dealing with large and sustained attacks.

such as the need to lock onto their targets before launch, limited range, and limited altitude coverage.

The presence of many scattered low-altitude threats often drives an adversary to higher-altitude operations. However, against layered defenses, operating at higher altitude might not always be a viable alternative. Fixed-wing aircraft can employ a set of tactics and technologies to minimize exposure to MANPADs and use countermeasures to reduce their effectiveness. Helicopters have more difficulty countering MANPADs, so MANPADs can be a very attractive defensive capability for infantry forces against helicopters, especially if discontinuities in the battle lines present opportunities for ambushes of helicopters.

MANPADs could play a role to supplement the air defense protection of ground forces in particular as part of a layered air defense. They are not an alternative for clearing large areas of airspace as envisioned in the air defense platoons considered in this report. The larger, heavier, AIM-9X and AIM-120 truck-mounted missiles allow a faster firing rate, a fire-and-forget missile with midcourse update capability, larger warheads, greater ranges, improved performance against countermeasures, and enhanced performance against cool targets, such as cruise missiles and UAVs. MANPADs could supplement these defenses and could be used by lighter ground forces for protection against helicopters in particular, but also in cases in which units were operating beyond the coverage of air defense platoons.

Vertical Takeoff and Landing

We considered including VTOL aircraft as an alternative to the JSF. For instance, the U.S. Marine Corps (USMC) and others currently operate Harrier AV-8Bs. They offer much more flexibility to operate from nontraditional locations than even a JSF STOVL does. Although a JSF STOVL can take off on a short runway, a Harrier can take off vertically with a light load or from a short runway with a full load. Thus a Harrier has an advantage over a JSF STOVL in one dimension. A vertical-takeoff capability would allow Taiwan to consider operating aircraft from numerous locations—not just highway strips but also

areas more like parking lots. This would greatly complicate the PLA attempts to target operating locations for these aircraft.

Although a Harrier offers this one advantage, it comes with many other disadvantages than a JSF and other fighter options the United States might consider making available to Taiwan. The Harriers are primarily designed for a close-air support mission in an environment in which air-to-air threats and long-range SAMs have been controlled, allowing operations above most SHORAD systems. In short, the Harrier was not designed to be an air-superiority system. Only the AV-8BII+ variant has a radar that would permit some air-to-air capability in the Strait. The JSF is not an air-superiority system either, but it does have a low RCS and a sophisticated radar and combat system that make it much better in the air than the other platforms consider in this report. A Harrier, in contrast, does not offer an upgrade to current Taiwan fighter aircraft. In addition, it would introduce several force management issues.

The age of the aircraft, its VTOL-driven design and focus on close-air support missions, the fact that the AV-8B production line is closed, and the fact that Taiwan has not previously operated these aircraft all combine to create numerous force management issues. If Taiwan were to acquire discarded USMC Harriers, they would be, at best, late 1990s-vintage aircraft. Taiwan's current fighters considered in this report were all introduced in the 1990s. Although Harriers might have a somewhat longer longevity than Taiwan's current systems, they would not be a long-term solution. Yet Taiwan would still have to work its way up a learning curve if it acquired them as the pilots train on the system and the ground crews adjust to the demands of an unfamiliar aircraft. Furthermore, operating costs might be difficult to accurately project. As the aircraft age, they normally get more expensive to maintain and operate. In addition, few Harriers would be operating in the entire world, so spare parts are likely to become very expensive. Furthermore, they would force Taiwan to continue to operate a mix of several different aircraft, which creates additional costs and management challenges.

Results of Other Forces Examined in the Air Sovereignty Vignette

The report compares four different potential force structure options. In selecting these four, we considered many other options, and others with an interest in Taiwan's security might have preferred some of those. To satisfy the curiosity of some, we present two other possible force structures and compare them with the four options analyzed in Chapter Three.

The Continuity option, as its name implies, represents much of the current trajectory of Taiwan's air force. It retains and retrofits all existing F-16A/Bs. In addition, it invests in further AIM-120 AAMs (576) to arm these refurbished fighters. To afford these changes, Taiwan would either have to increase its spending on air defense or have to divest from existing systems. In this option, we divest the entire Mirage force, which creates a US\$3.7 billion savings.

Another option we examine here is the Mixed New F-16C/D Force. Taiwan had previously expressed interest in acquiring 66 new F-16C/D aircraft; however, both the George W. Bush and Barack Obama administrations discouraged Taiwan from making a formal request. Although the proposed retrofit will give some of the same capabilities as the F-16C/D, acquiring new aircraft would allow Taiwan to operate these about 20 years further into the future than the retrofit aircraft. To make this a more balanced option, the existing aircraft are all retired to free substantial resources to invest in SAMs, which allows Taiwan to field 21 air defense platoons and four additional Patriots in this option. Table D.1 summarizes all six force structure options, with the two added options in the two rightmost columns.

We now reproduce two figures from Chapter Three (Figures 3.5 and 3.10) and add to them the two new options for comparison, shown in Figures D.1 and D.2. The first of these figures compares the options with current-day threats. One of the most important factors these figures reveal is the slope of the curves and when the size of the force drops below a point at which filling defensive CAPs around all of Taiwan becomes impossible. Compared with the Baseline option, the Continuity option, which features 144 F-16 retrofits, changes the slope of the drawdown curve very modestly, not enough to significantly change the number of engagements of the type posited in the Air Sovereignty vignette that this option could sustain. The Mixed New F-16C/D Force option does not change the slope of the drawdown curve from that of the Mixed Force option because we assess the F-16 retrofit and F-16C/Ds to have comparable capabilities, but there is a major difference in force size between these two options (144 F-16 retrofit versus 66 F-16C/Ds).

When compared with future threats (the J-11B upgrade [J-16], armed with improved PL-15 AAMs), as we did in Chapter Three, all the options are drawn down more quickly. The relative performance of the Taiwan force structure options do not change, with the Continuity option achieving only a modest gain compared with the Baseline option, and the Mixed New F-16C/D Force tracking with the Mixed Force. Against both current and future threats, only the JSF-Only Force option changes the slope of the drawdown curve in Taiwan's favor. The problem with that option, as discussed in Chapter Three, is that Taiwan cannot afford to buy large numbers of them under current budget conditions, and the United States has not indicated that it would be willing to allow a JSF sale to Taiwan.

This appendix completes the analysis of options that include changes to Taiwan's fighter aircraft force that have been discussed in news articles and conferences in recent years. These results do not alter any of the comments in Chapter Four regarding Taiwan's air defense choices. In fact, they reinforce the message that small capability advancements do not address the quickly modernizing threat that Taiwan faces and underscore that rather forceful change is in order.

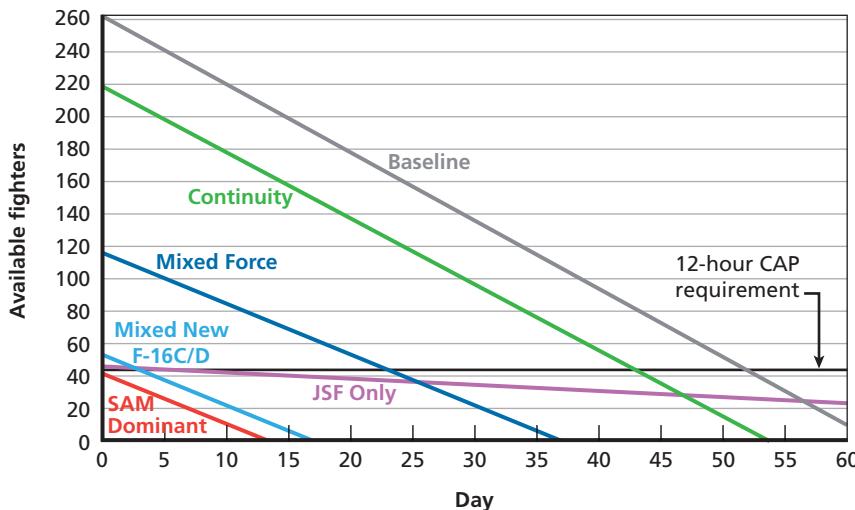
Table D.1
Force Structure Options

Option	Baseline	Mixed Force	JSF-Only Force	SAM-Dominant Force	Continuity	Mixed New F-16C/D Force
Retrofit F-16A/B	144	144	0	50	144	0
F-16C/D new	0	0	0	0	0	66
F-CK/IDF	127	0	0	0	127	0
Mirage 2000-5	57	0	0	0	0	0
JSF STOVL (F-35B)	0	0	57	0	0	0
AIM-120 (additional)	576	2,676	228	1,800	1,096	2,364
PAC-3 (additional)	0	4 launchers, 300 interceptors	0	13 launchers, 975 interceptors	0	7
Air defense platoons	0	21	0	40	13	21
Modernization investment estimate (billions of BY 2013 US\$) ^a	6.7	6.7	6.7	6.7	6.7	6.7
20-year cost difference (billions of BY 2013 US\$)	-2.008	-0.882	-0.033	-0.480	-1.729	-0.406

NOTE: Negative cost numbers represent savings.

^a This is an estimate of new military investment in air defense capabilities over 20 years. It is derived in Chapter Two.

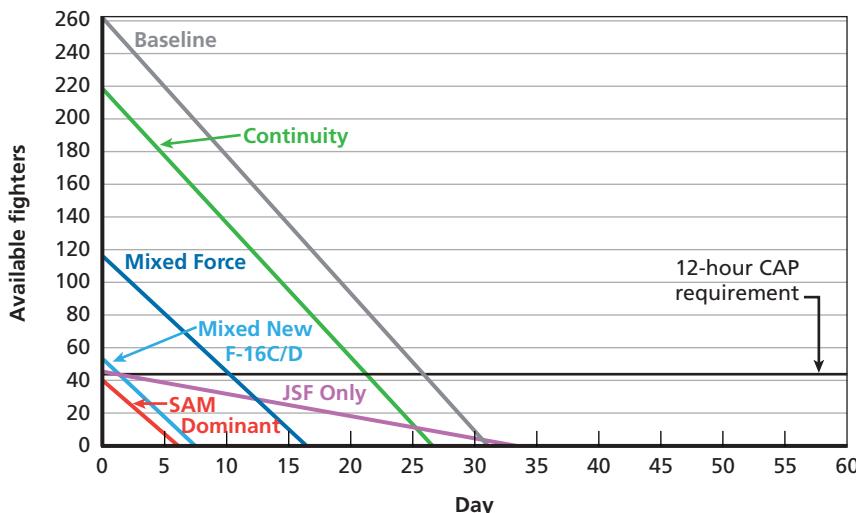
Figure D.1
Fighter Attrition over Time: High-Intensity Conflict Versus Current Threats



NOTE: *High intensity* here means seven CAPs engaged per day. Baseline has 328 F-16 retrofit, F-CK/IDF, and Mirage aircraft. Continuity has 271 retrofitted F-16 and IDF aircraft. Mixed Force has 144 retrofitted F-16 aircraft. Mixed New F-16C/D has 66 F-16C/D aircraft. JSF Only has 57 F-35B aircraft. SAM Dominant has 50 retrofitted F-16 aircraft. All vignettes assume that 80 percent of the force is available for combat.

RAND RR1051-D.1

Figure D.2
Fighter Attrition over Time Versus PL-15 Threat: High-Intensity Conflict Versus Developmental Threats



NOTE: High intensity here means seven CAPs engaged per day. Baseline has 328 F-16 retrofit, F-CK/IDF, and Mirage aircraft. Continuity has 271 retrofitted F-16 and IDF aircraft. Mixed Force has 144 retrofitted F-16 aircraft. Mixed New F-16C/D has 66 F-16C/D aircraft. JSF Only has 57 F-35B aircraft. SAM Dominant has 50 retrofitted F-16 aircraft. All vignettes assume that 80 percent of the force is available for combat.

RAND RR1051-D.2

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Taiwan faces one of the most difficult air defense problems in the world. Because of that, it cannot easily look to how other nations have invested in air defenses to guide its force structure decisions. What makes Taiwan's air defense problem so difficult is the combination of its proximity to China and the massive investments that the People's Republic of China has made in a range of systems that threaten Taiwan's aircraft. China now has the capability to destroy all of Taiwan's aircraft at their bases. Although some aircraft might be safe in caves, Taiwan cannot use them from those shelters for sustained combat operations. Thus, Taiwan needs to rethink how it can accomplish its air defense goals in a major conflict without heavy reliance on its fighter aircraft. Fighter aircraft are not the only element of Taiwan's air defense; surface-to-air missiles are the other major element. Still, air defense in a major war is only one possible category of demands for Taiwan's air defenses. A variety of more-limited military conflicts could draw on air defense capabilities. This report analyzes Taiwan's options for allocating future resources for air defense capabilities. It describes the essential air defense problem posed by the People's Liberation Army, characterize the current capabilities and level of funding that Taiwan invests in air defense, and then develop several alternative investment strategies. The authors then test those investment strategies in three vignettes that span the range of conflict, from quite limited coercive uses of force to a full invasion.



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